SURVEY OF PHYTOSEIIDS (ACARI: PHYTOSEIIDAE) ON THE CENTRAL COAST OF CALIFORNIA

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ABSTRACT

Survey of Phytoseiids (Acari: Phytoseiidae) On the Central Coast of California

Maria Elena Murrietta

Phytoseiids were collected March through November, 2006 and 2007, from leaf samples of avocados, cherimoya, caneberry, grape, and strawberry from a combined total of 24 sites. The most diverse collection of phytoseiids was identified on grape with seven different genera and 12 different species followed by caneberry with 7 genera and 7 species. Strawberry was the least diverse with three genera and three different species. The most significant presence of type I and type II phytoseiids were located on caneberry and strawberry while avocado, cherimoya and grape were dominated by type IV species. Reasons for the difference in diversity could be attributed to the availability of preferred hosts, alternate food sources, and the effectiveness of augmentative releases and pesticide applications.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

LIST OF APPENDIX FIGURES

CHAPTER I

INTRODUCTION

Phytoseiidae is a family of predatory mites that feed on various other mites and small insects (Croft et al., 1997; McMurtry & Croft, 1997). Certain species of phytoseiid mites are recognized in the agriculture industry as effective biological control agents of tetranychid mites, one of the most serious pest mite groups in agriculture (Zhang, 2003) and have been utilized as biological control agents in agriculture worldwide for more than 50 years (Huffacker and Flaherty, 1966; van Lenteren, 1988; Gerson & Weintraub, 2007; Croft et al., 1997; McMurtry & Croft, 1997). Many species occur naturally in cropping systems and some species have been studied, reared in laboratories, and are commercially available for augmentative releases to enhance existing populations (McMurtry & Scriven, 1965a; van Lenteren, et al., 1997; Warner & Getz, 2007). The feeding habits of phytoseiids range from specialized predators of specific species to general predators that can successfully feed and reproduce on tetranychids, small insects, and pollen (McMurtry & Croft, 1997).

Purpose of Study

The purpose of this survey was to identify phytoseiid species and their correlation, if any, with tetranychid pest mites during a growing season. Multiple field locations of avocado, cherimoya, caneberry, grape and strawberry were surveyed in 2006 and 2007. This survey included a quantitative account of phytoseiid species and tetranychid pests.

Commercial pesticide products have changed and regulations have become more restrictive during the past 60 years in California agriculture (Federighi, 2001). These changes affected application practices which resulted in a shift towards the use of less toxic pesticides and less reliance on broad spectrum pesticides (Ridgeway & Inscoe, 1998). This industry wide shift may have had positive effects on existing phytoseiid predators in agricultural systems. Data on existing predatory mites would provide growers with an understanding of biological control activity, help them make more informed pest management decisions, and adopt practices to enhance phytoseiid populations.

Phytoseiid predators exist in both managed and natural systems and perform varying degrees of biological control activity. They have been studied and reared since the 1950s for their abilities to manage destructive crops pests (Ridgeway & Inscoe, 1998). Differences in prey preference, reproductive patterns and response to plant structures exist throughout the phytoseiid family, between genera, and among species, which bring about inherent differences in their abilities and limitations as biological control agents. Conducting field surveys of phytoseiids can provide the details needed to accurately evaluate a predator's potential, provide information where it is lacking, and amend the current literature when necessary.

CHAPTER II

LITERATURE REVIEW

Tetranychidae

Tetranychidae are phytophagous web spinning spider mite pests and have been identified in fruit, vegetable and fiber crops worldwide (Van de Vrie, 1985) spanning 194 plant families including *Rosaceae*, *Solanaceae*, *Brassicaceae*, *Asteraceae*, *Vitaceae*, and *Lauraceae* (Bolland et al., 1998). The Entomological Society of America's Common Names of Insects Database lists 10 major genera of Tetranychidae that damage agricultural crops: *Bryobia*, *Eotetranychus*, *Oligonychus*, *Panonychus*, *Petrobia*, *Platytetranychus*, *Pseudobryobia*, *Schizotetranychus*, *Tetranychina*, and *Tetranychus*. Spider mite damage ranges from plant-weakening to death. Feeding typically occurs on leaves, but mites also will feed on cotyledons, shoot tips, fruits and flowers (Tomczyk & Kropczynska, 1985).

Many species feed on the underside of leaves; however, some species prefer the upper surfaces while others will feed on both (Tomczyk & Kropczynska, 1985). Spider mites use piercing/sucking mouthparts to penetrate the plant tissue and siphon the contents of the cell. The stylet pierces the spongy mesophyll tissue and sometimes the lower parenchyma layer depending on the length of the stylet and density of the pest population (Tomczyk & Kropczynska, 1985). The immediate damage occurs when plant cells are punctured (Mothes & Seitz, 1982). Cell degradation results in a stippled appearance on the leaf surface which is the common sign of spider mite damage. Heavy populations of spider mites can cause leaf curling, leaf burning and eventual necrosis (Tomczyk & Kropczynska, 1985).

Tetranychid Webbing

Tetranychid species spin webs of varying complexities (Saito, 1983) and phytoseiids differ in their ability to penetrate and successfully maneuver about the webbing (Sabelis & Bakker, 1992). Webbing is formed by a silk producing gland located in the pedipalps. A protein secretion is released from the rough endoplasmic reticulum and carried through to the spinneret (Mothes & Seitz, 1982).

Webbing protects all life stages of the colony by regulating climactic factors (Hazan et at., 1975; Davis, 1952), deterring predation (Sabelis, 1985) and by aiding in dispersal (Gerson, 1985). Temperature and relative humidity (RH) regulation is necessary for developing colonies housed beneath the webbing. Extremely high and low temperatures and RH cause a decrease in web production, thereby reducing the survival rate of a developing generation (Sabelis, 1985). Optimal conditions for web production and development have been documented as 24˚C and 38% RH (Hazan et al., 1975).

Dispersal occurs when silk is spun and used as a rope to propel the spider mite to an alternate leaf surface (Gemrich et al., 1976). This behavior, described as spin down (Gemrich et al., 1976), enables spider mites to relocate when needed, such as when chemical residues are detected on leaf surfaces. Web strands and wind currents can propel mites to a more suitable location (Gerson, 1985). Wind can also initiate spin down by blowing mites off the leaf surface requiring them to spin a web to direct their landing onto another leaf (Fleschner et al., 1956; Gemrich, et al., 1976).

Tetranychids have been categorized according to the complexity of the web they spin. There are three major types of webbing produced by spider mites: little web (LW), complicated web (CW) and web nest (WN) (Saito, 1983). The genera *Aponychus*, *Eurytetranychus*, *Panonychus* and *Yezonychus* make up the LW category of mites that spin web sparingly and display the simplest structure of the three types (Saito, 1983). Most species use webbing for migration activities (Fleschner et al., 1956), some spin just enough web to secure eggs to a leaf, and others spin no web at all (Saito, 1983). *Panonychus* species, for example, do not produce any webbing (Saito, 1983).

The term “nest” of the WN type refers to the accumulation of webs over depressed areas of the leaf usually near the midrib. Spider mites of the WN category spin web while they walk and produce a greater quantity of web than LW species. Producers of web nests walk on top of the mat of webbing to prevent falling from the leaf, particularly from smooth leaves. Feces and cast cuticles are deposited among the threads to keep the leaf surface and feeding area clear of debris. *Eotetranychus* and *Oligonychus* species are included in the WN group (Saito, 1983).

The CW web type is described as three-dimensional and displays the most complex design. This type of web is spun in an irregular fashion, resulting in a network of crossed strands that serve many of the same functions as the WN. These species also spin web while they walk on top of the webbing. Certain species of *Eotetranychus* and *Tetranychus* produce CW type webbing (Saito, 1983).

Tetranychid Life Cycle

The spider mite lifecycle includes the egg, larva, protonymph, deutonymph and adult stage (Crooker, 1985). Each immature stage feeds before entering quiescent periods of nymphochrysalis, deutochrysalis and teleiochrysalis (Van de Vrie et al., 1972). During this resting period, the spider mite attaches itself to the leaf while the next stage of development occurs within the existing integument, which then splits and the spider mite emerges (Crooker, 1985).

Larvae have only 6 legs. The quiescent period begins after sufficient feeding (Malais & Ravensberg, 2003). The legs are then withdrawn and development of the first nymphal stage, the protonymph, begins (Malais & Ravensberg, 2003). Protonymphs have 8 legs. Quiescence follows and feeding and development of the second nymphal stage, deutonymph, begins (Malais & Ravensberg, 2003). Deutonymphs begin to develop distinguishing features. The final resting period begins, followed with the development of an adult spider mite. Adult male and females spider mites can be distinguished by shape and overall size. Males have a narrowed body shape with a pointed posterior while females are slightly larger with a more rounded body shape (Malais & Ravensberg, 2003).

Tetranychid Feeding

Yellow stippling visible on the leaf surface is a sign of spider mite feeding. Mites prepare to feed by elevating the posterior with the back legs, angling their bodies and pressing their mouthparts to the leaf surface (Tomczyk & Kropczynska, 1985). Spider mites target the spongy mesophyll layer of leaf tissue and sometimes the lower parenchyma layer, depending on the length of the stylet (Tomczyk & Kropczynska, 1985). The stylet slides back and forth and punctures the tissue repeatedly. Cell contents, including the chlorophyll, are siphoned through the food channel and ingested. Cell degradation, specifically the removal of chlorophyll, results in the stippled appearance on the leaf surface (Tomczyk & Kropczynska, 1985). Disruption and removal of chlorophyll results in the reduction of photosynthesis and hinders plant growth. Tomato and cucumber leaves with 30% of the surface infected with spider mites can result in whole plant loss (Malais & Ravensberg, 2003).

Tetranychid Mouthparts

Tetranychid have mouthparts adapted for feeding on plants. Some terms used to describe their mouthparts are unique to this group and are not used to describe the mouthparts of the other mite families (Andre & Remacle, 1984).

Collectively, the mouthparts are referred to as the gnathosoma. The major structures of the gnathosoma include the pedipalps and chelicerae. Pedipalps are two-segmented appendages with the primary purpose of locating and handling food. The eupathidium or spinneret is located on the terminal segment of the palps and is found only among web-spinning individuals (Andre & Remacle, 1984). The muscles that regulate the pedipalps and the unicellular silk gland are located at the base of the gnathosoma.

Chelicerae are five-segmented and function as piercing/sucking mouthparts (Andre & Remacle, 1984). The basal joints of the chelicerae are fused to form the stylophore, a capsule-like structure that houses a moveable digit. The moveable digit has been modified in tetranychids into a needle-like stylet that protracts and retracts to puncture plant cells (Zhang, 2003). Protraction of the stylet is an active function supported by protracting muscles. Retraction of the stylet is a passive response as there are no retractor muscles. The distal ends of the chelicerae open to a hollow pathway, or food channel, that siphons plant cell contents (Andre & Remacle, 1984). The basal end of the food channel is connected to the pharynx that functions as a pump to extract plant cell contents (Zhang, 2003).

Pesticide Effects on Tetranychids

Pesticides can directly and indirectly cause the pest mite population to increase (Gemrich et al., 1976). Directly, chemicals can trigger a physiological stimulation resulting in spin down (Gerson, 1985; Rudd, 1997). Spider mites in field crops have an added advantage over greenhouse grown and other protected crops as they can be dispersed by wind. Pyrethroids and wind-aided dispersal have been shown to induce spin down resulting in spider mite outbreaks in different areas of a field (Gerson, 1985). Additionally, tetranychids experience hormoligosis, the phenomenon known as pest resurgence where the target pest population increases reproduction after chemical applications (Morse, 1998).

Pesticides can indirectly cause an increase in spider mite populations by killing non-target predators, including phytoseiids (Croft, 1990; Cross & Berrie, 1994; Flaherty & Huffacker, 1970; Irigaray et al., 2007). Residual effects of Fenpyroximate resulted in 100 % mortality to phytoseiids *Phytoseiulus persimilis* Athias-Henriot and *Galendromus* (*Metaseiulus*) *occidentalis* Nesbitt 72 hours after application (Irigaray et al., 2007). Abamectin reduced the fecundity of *G. occidentalis* 36 days after application on strawberries (Irigaray et al., 2007). Reducing the population of natural enemies allows pests to reproduce with a lower risk of predation (Metcalf, 1980). Pest resurgence is argued to be an ecological function that selects for tolerant individuals that can ultimately lead to chemical resistance among pests and predators (Hardin et al., 1995).

Phytoseiidae

Phytoseiids are utilized in the agriculture industry as biological control agents of Tetranychidae, the family that contains economically important phytophagous spider mites. Phytoseiids have been used for this purpose since 1956 when the management of spider mites using predaceous mites was demonstrated on strawberry in California (Ridgeway & Inscoe, 1998). Phytoseiids have since been surveyed and evaluated as biological control agents in avocado (McMurtry et al., 1985; Kerguelen & Hoddle, 1999), citrus (McMurtry, 1977; Grafton-Cardwell & Ouyang, 1995), grape (Kinn & Doutt, 1972a; Tixier et al., 2000), cotton (Colfer et al., 2003), fruit orchards (Monetti & Fernandez, 1995), caneberry (Roy et al., 2005; Linder et al., 2003), and various greenhouse grown crops (Malais & Ravensberg, 2003; Opit et al., 2004). There are currently 16 species of phytoseiids mass-reared and commercially available for use in biological control programs (Daar et al., 1997; Knapp et al., 2013).

Physical Characters

Phytoseiid species vary in behavior, feeding habits and physical characters that impact their efficacy as biological control agents of tetranychid spider mites. Specifically, behavioral and anatomical differences result in differing levels of efficacy among species (Huffaker & Flaherty, 1966; Chant & Fleschner, 1960).

Associations have been suggested between phytoseiid chaetotaxy, or setal patterns, and their ability to successfully navigate CW type webbing and, therefore, their effectiveness as predators of tetranychids. Long setae in the medial location on the dorsal shield, j4–j6 and J2, may correlate to ease of mobility (Sabelis & Bakker 1992). See Figures 29 and 30 for setal notations. Long setae in the right location can minimize direct contact between sticky web strands and the body of the predator (Sabelis & Bakker 1992). Otherwise, the predator can become entangled and unable to pursue prey.

Certain physical characters enable phytoseiids to manage complex plant structures and leaf architecture. The presence of domatia or trichomes on leaves can either impede a predator's movement and searching ability, similar to the presence of spider mite webbing (McMurtry and Croft, 1997), or provide refuge and increase reproduction (Grostal & O'Dowd, 1993). Phytoseiids, including *Amblydromalus limonicus* Garman & McGregor, preferred to lay eggs within the protected area of domatia located in leaf vein axils (Grostal & O'Dowd, 1993). Phytoseiids capable of navigating both dense webbing and leaf hairs have long setae along the margin of the dorsum (Sabelis and Bakker, 1992; McMurtry & Croft, 1997), while phytoseiids with short dorsal setae have been correlated to plants with glabrous leaves (McMurtry & Croft, 1997). Duso (1992 and 1993) suggests that phytoseiids found on hairy leaves are relatively small with narrow bodies and long legs such as *Typhlodromus pyri* Scheuten and *Amblyseius aberrans* Oudemans, both of which have been abundant on grape varieties with dense leaf hair.

Phytoseiid Behavior

Distribution patterns describe the location on the plant or leaf the organism prefers. Some phytoseiids seek locations that are contrary to tetranychids while others occupy a similar space (Chant & Fleschner, 1960). *Typhlodromus pyri* was evaluated for its ability to manage the pest population of *Panonychus ulmi* Koch in England orchards (Chant & Fleschner, 1960). The performance of *T. pyri* was compared to that of two common phytoseiids in southern California orchards, *E. hibisci* and *A.* (*Typhlodromus*) *limonicus.* All three were determined to be facultative predators, able to live and reproduce successfully on plant foods (Chant & Fleschner, 1960). *Typhlodromus pyri* prefers younger apple leaves and is usually found on the underside of the leaf, along the midrib or other larger veins, on apple leaves in early summer. *Panonychus ulmi* is found on older leaves with most of the population on the upper surface of leaves (Chant & Fleschner, 1960). Distribution differences between the predator and pest made *T. pyri* incapable of being an effective predator in apple orchards. The same *Typhlodromus* species was evaluated in a greenhouse environment and it was found to be an effective predator of spider mites in that setting. The predator exhibited greater distribution over the upper and lower leaf surfaces in the greenhouse and provided effective control of plant-feeding mites. Distribution patterns were observed for *E. hibisci* and *A. limonicus* in southern California citrus and avocado orchards which displayed similar patterns to that of *T. pyri* on apples in England (McMurtry & Johnson, 1965). However, avocado brown mite (*O. punicae)* in California was distributed much the same as both phytoseiid species. These phytoseiids were, therefore, able to manage pest populations partly due to similar distribution patterns.

Reproductive potential and development time are key factors to consider when evaluating a predator's potential. Early observations indicated that *E. hibisci* was a key predator in citrus and avocado orchards and often coexisted with *A. limonicus* (McMurtry & Scriven, 1965b). An analysis of these two closely related species found that *A. limonicus* had a higher rate of reproduction and a shorter development time than *E. hibisci* when feeding on *P. citri* and *T. cinnabarinus* (McMurtry & Scriven, 1965b). Another study found that *E. hibisci* preyed on and successfully reproduced on *P. citri*, *O. punicae*, and *E. sexmaculatus*, but not on *T. cinnabarinus* (McMurtry & Scriven, 1965b). A separate survey of avocado orchards confirmed that a pollen diet stimulates the reproduction rate of *E. hibisci* independently of tetranychids (McMurtry & Johnson, 1965). Peaks in egg production were associated with flowering and the availability of pollen rather than the presence of tetranychid mites. Furthermore, *E. hibisci* exploited pollen from trees within the orchard and from pollen blown in from certain neighboring plantings, whereas *T. pyri* successfully reproduced only on pollen grains from resident trees that were still attached to anthers (Dosse, 1961). Such details define species specific behaviors and emphasize the level of research needed to understand their biology.

Predators feed on sources that maximize their reproductive potential (Sabelis, 1985). *Euseius tularensis* Congdon*, E. stipulatus* Athias-Henriot and *E. hibisci* were examined in a laboratory and given pacific spider mite (*Tetranychus pacificus* McGregor), citrus red mite, (*Panonychus citri* McGregor) and pollen to determine the ovipositional rates resulting from different foods (Zhimo & McMurtry, 1990). Mean oviposition rate was calculated as the number of eggs laid per day, per female, per 10-day period. A diet of *P. citri* alone produced the lowest oviposition rate with 0.61, 0.78, and 0.64 eggs laid per day by *E. tularensis, E. stipulatus* and *E. hibisci*, respectively. A diet of *T. pacificus* alone resulted in mean ovipositional rates of 1.05, 1.48, and 1.83 eggs laid per day, respectively. The pollen diet produced rates that were consistently higher than the diet of both mite species at 1.22, 1.25 and 1.80 eggs laid per day, respectively. The only deviation was for *E. hibisci* which showed nearly the same oviposition rate while feeding on *T. pacificus* and pollen. The ability to supplement a diet with pollen when the primary food source is scarce is beneficial to a predator's survival rate (Zhimo & McMurtry, 1990).

Pesticide Effects on Phytoseiids

It is largely accepted that some pesticides have a the desired effect on tetranychids, but are detrimental to phytoseiids (Castagnoli et al., 2005;Jeppson et al, 1975; James, 2003).

Susceptibility to pesticides varies among phytoseiid species, but the results of such studies may be inaccurately reported or generalized. Congdon & McMurtry (1985) found that early reports of insecticide resistance of *E. hibisci* in San Joaquin Valley citrus were likely based on *E. tularensis* individuals that were presumed to be *E. hibisci*. This correction was based on prior knowledge of the favored region and host plant and level of pesticide resistance indicative of *E. tularensis*. *Euseius tularensis* is known to exist in warmer interior regions, mostly on citrus and has demonstrated a greater resistance to insecticides than *E. hibisci* (Zalom et al, 1985; Congdon & McMurtry, 1985; Grafton-Cardwell & Ouyang, 1995). An additional study by McMurtry and Flaherty (1976) monitored a walnut orchard sprayed with azinphosmethyl for codling moth to determine the effects on phytoseiids. It was found that populations of *G. occidentalis* and *P. citri* were not greatly reduced after the spray application, while *E. hibisci* was less tolerant of this chemical.

The level of susceptibility varies among chemicals. Imidacloprid and pyrethrins have been shown to increase fecundity of *T. urticae*, decrease fecundity of *N. californicus* McGregor (Castagnoli et al., 2005) and result in 100% kill of *G. occidentalis* (James, 2003). *Galendromus occidentalis* is an important predator of spider mites (Irigay & Zalom, 2006) and has been recognized as such since the 1950s (Huffaker & Flaherty, 1966). Two common miticides, fenpyroximate and extoxazole, are detrimental to *G. occidentalis* and their effects persist more than 30 days; acequinocyl and abamectin are less persistent. *Euseius stipulatus* and *E. hibisci* are closely related species but have demonstrated dissimilar responses to dicofol, an organochlorine miticide. *Euseius hibisci* was 41 times more susceptible to dicofol than *E. stipulatus* (Jeppson et al, 1975).

Numerous other studies have been conducted to evaluate pesticide effects on phytoseiids with various chemical classes commonly used on grape (Grape Pest Management Guidelines, 2014), avocado (Avocado Pest Management Guidelines, 2014.), strawberry (Strawberry Pest Management Guidelines, 2010), and caneberry (Caneberry Pest Management Guidelines, 2014) among other tree and row crops in California. The level of toxicity to predatory mites in these reports is based solely on the response of *G. occidentalis*. This phytoseiid was used as the standard to rate the tolerance of all other phytoseiids. Analyses of individual species would be necessary to accurately determine the effects of insecticides and miticides on the many other phytoseiid species that exist in each cropping system.

Phytoseiid Types

Phytoseiids have been categorized into four major types - type I, type II, type III and type IV - according to their food preferences and plant distribution among other behaviors and adaptations that determine their suitability as biological control agents (McMurtry & Croft, 1997). Types I and III have been further divided into subcategories according to their preferred mite prey and habitat, respectively (McMurtry et al., 2013). Some genera have been included in more than one type category as needed to acknowledge behavioral differences among species. Lesser known genera have not been studied to the degree necessary to include them in these categories.

Type I Phytoseiids

Type I phytoseiids, are subdivided into three subtypes – I-a, b, and c – according to their preferred mite prey. Subtype I-a is comprised of species in the genus *Phytoseiulus* and are specialized feeders of *Tetranychus* species (McMurtry & Croft, 1997, McMurtry et al., 2013).

Anatomical features allow *P. persimilis* to penetrate the dense CW type webbing of *T. urticae* (Jackson, 1974). Long legs and long dorsal setae (Fig. A32) are comparatively longer than other genera and enable *P. persimilis* to maneuver through webbing without getting entangled in sticky web (Jackson, 1974). In spite of this capability, *P. persimilis* has been observed to be an ineffective manager of *T. urticae* on solanaceous plants, likely due to the presence of trichomes (Krips et al., 1999). Conversely, *Phytoseiulus macropilis* Banks appeared to exploit the presence of CW type webbing, using it to avoid contact with trichomes of tomato leaves (Sato, 2011).

Phytoseiulus persimilis searches randomly among plants for its preferred host, yet shows strong aggregation within a plant and among leaflets once locating the host (McMurtry & Croft, 1997; Zhang & Sanderson, 1993). The tendency to aggregate among the leaves correlates to the behavior of *T. urticae* (Zhang & Sanderson, 1993). The relationship between *P. persimilis* and *T. urticae* demonstrates a typical predator-prey relationship with the predator population increasing in response to an increase in *T. urticae* and ultimately causing a decline in the pest population (Zhang and Sanderson, 1993). Consuming *T. urticae* results in the highest reproductive potential for *P. persimilis*, compared to other mite hosts, with a mean oviposition rate of 2.66 eggs per female, per day (Zhang, 1995). The rate of kill for *P. persimilis* is one tetranychid per hour (Zhang, 1995). Development time from egg to a reproductive female is 3.8 days (McClanahan, 1968).

Species in subtype I-b are predators of producers of WN-u type webbing and includes species of *Oligonychus, Schizotetranychus* and *Stigmaeopsis* (McMurtry et al., 2013). *Typhlodromus (Anthoseius) bambusae* Ehara is used in China as a predator of *Schizotetranychus celarius* Banks, a bamboo mite (Zhang et al., 1999).

Subtype I-c predators are specialized predators of tydeoids and includes species of *Paraseiulus* and *Typhlodromina* (McMurtry et al. 2013). McMurtry has observed *Typhlodromina eharai* Muma and Denmark preying on *Tydeus californicus* Banks (Acari: Tydeidae) on avocado in California (unpublished observation). Tydeoids are considered to be suitable alternate food sources for a variety of phytoseiids, including *G. occidentalis*, when its preferred host population is low (McMurtry et al., 2013, Knop and Hoy, 1983).

Type II Phytoseiids

Type II phytoseiids are selective predators of tetranychids associated with CW web producing spider mites such as *T. urticae, T. cinnabarinus, E. sexmaculatus, O. perseae* and *O. punicae* (McMurtry & Croft, 1997). Type II phytoseiids also feed on eriophyoids (gall mites) and tydeiids (fungal feeding mites) (McMurtry & Croft, 1997). Examples of type II phytoseiids include *G. occidentalis*, *G. annectans*, *N. californicus*, and *N. fallacis*. The reproductive potential of type II predators is slightly less than type I at three eggs laid per day (Zhang & Sanderson, 1995). *Galendromus occidentalis* and *N. californicus* are effective predators, both naturally occurring and commercially available, in agricultural field crops such as strawberries (Strawberry Pest Management Guidelines, 2010). The dorsal setae of type II phytoseiids are considered long but these features do measure shorter than that of type I phytoseiids (McMurtry & Croft, 1997). See Figures A39 and A28 for setal patterns of *G. occidentalis* and *N. californicus*. *Galendromus occidentalis* has demonstrated a predator-prey relationship on grape, increasing along with the pest population of *Tetranychus mcdanieli* McGregor and later causing a decrease (Prischmann et al., 2006). Kinn and Doutt (1972b) also found *G. occidentalis* to have a similar distribution pattern as *E. willamettei* which prefers the upper and lower surfaces of shaded leaves.

Type III Phytoseiids

Type III phytoseiids are general predators that feed on tetranychids, eriophyids, tydeoids, small insects, pollen grains, plant exudates and fungi (McMurtry & Croft, 1997; McMurtry et al., 2013). These species are unable to penetrate the dense covering of CW type webbing due to comparatively short dorsal setae (McMurtry & Croft, 1997); therefore, the space they occupy within a plant is not consistently correlated to the space occupied by web-spinning spider mites. See Figures A2 and A51 for setal patterns of *A. limonicus* and *Metaseiulus flumenis* Chant.

Type III is a large category subdivided into 5 groups based on habitat. The first division, subtype III-a, live on pubescent leaves and includes species within the genera

Kampimodromus, Typhlodromus, Typhlodromalus, *Paraphytoseius* and *Phytoseius* (McMurtry et al., 2013). Characters such as a laterally flattened idiosoma, short setae and long gnathosoma allow these predators to maneuver about pubescent leaf surfaces. *Typhlodromus pyri* is found to be most abundant in systems receiving limited pesticides (Hadam et al., 1986) and on grape varieties with leaves with trichomes (Loughner et al., 2008). Loughner observed that less prey specific predators, such as *T. pyri*, are likely to demonstrate a delay in their response to a prey population since they are able to leave one system to search for alternate hosts when the prey species is lacking. This delayed response and ability to exploit alternate hosts is contrary to the behavior demonstrated by type 1 specialist species.

Subtype III-b phytoseiids are found mostly on glabrous leaves and includes species of *Amblyseius*, *Amblydromalus* and *Neoseiulus* (McMurtry et al., 2013). *Amblydromalus limonicus* has been recorded in California's coastal regions on low growing herbaceous plants and on citrus, avocado and walnut trees where it was observed to be a predator of *P. citri*, *E. sexmaculatus* and *O. punicae* (McMurtry and Scriven, 1964; McMurtry et al., 1971). *Amblydromalus limonicus* is commercially available for control of egg and larval stages of thrips and whitefly on various protected crops (Knapp et al., 2013). *Neoseiulus cucumeris* Oudemans is commercially available for management of thrips and *N. barkeri* Hughes is available for management of tarsonemid mites such as broad mite, *Polyphagotarsonemus latus* Banks on sweet peppers (Weintraub et al., 2003).

Subtype III-c phytoseiids prefer confined places on galled leaves of dicotyledons such as willow and poplar trees. This subgroup is largely represented by the *desertus* group of *Neoseiulus* which are often associated with gall forming eriophyoids (McMurtry et al., 2013; Prischmann et al., 2005). These species have not been studied to evaluate their utility as biological control agents.

Subtype III-d phytoseiids inhabit protected spaces on monocotyledons and have been found between leaf sheaths and bracts on grasses and the surface of coconut fruits (McMurtry, 2010; McMurtry et al., 2013). This group is largely represented by the *paspalivorus* species group of *Neoseiulus,* a group of small flat mites with short legs that includes the closely related *N. baraki* and *N. paspalivorus* DeLeon.

Subtype III-e phytoseiids are found in soil and litter habitats and includes species of *Amblyseius, Arrenoseius, Chelaseius, Graminaseius, Neoseiulus* and *Proprioseiopsis* (McMurtry et al., 2013). Little information is available regarding this group.

Type IV Phytoseiids

Type IV is comprised of the genera *Euseius*, *Iphiseius* and *Iphiseiodes* (McMurtry & Croft, 1997; McMurtry et al., 2013). There are more than 200 known species of *Euseius*, few of *Iphiseiodes* and only one *Iphiseius* (McMurtry et al., 2013).These species feed primarily on pollen, but will also feed on mites, thrips, leaf sap and other small insects (McMurtry & Croft, 1997). *Iphiseius degenerans* Berlese is commercially available for control of whiteflies (McMurtry et al., 2013), although the reproductive potential is typically highest when pollen is the main food source (McMurtry & Croft, 1997). Anatomical adaptations of the *Euseius* make it possible to retrieve and manipulate small pollen grains. The chelicerae are short and have a convex bend at the tip of the digit

(Flechtmann & McMurtry, 1992). *Euseius* species can exploit the contents of 100 pollen grains in one hour and spend an average of less than ten seconds on each pollen grain (Flechtmann & McMurtry, 1992).

Euseius species will forage randomly on both the upper and lower leaf surfaces (McMurtry & Croft, 1997) and their intraplant distribution pattern is not generally correlated to that of spider mites (McMurtry, 1992). Short setal lengths are not well adapted for maneuvering among sticky webs (See Figures A17 and A9 for setal patterns of *E. stipulatus* and *E. hibisci*), one exception being *E. victoriensis* Womersley which is reported to be an effective predator of *T. urticae* in Australia (James, 2001). Generally, type IV species are more suited for predation of non-web spinning mites such as *Panonychus* species in tree crops (Hoddle, 1998, Avocado Pest Management Guidelines, 2014). *Euseius* species are not commercially available; however, they are important predators of *P. citri*, a tetranychid mite that produces little webbing (Congdon & McMurtry, 1985) and is a major pest on citrus in California's San Joaquin Valley (Congdon & McMurtry, 1985; McMurtry, 1977; McMurtry, 1985). *Euseius stipulatus* can colonize and spread to other trees and has demonstrated a predator-prey relationship with *P. citri* by directly responding to the pest population increases and causing a subsequent decline (McMurtry, 1977). McMurtry (1992) found the density of *P. citri* to be lower in orchards where releases of *Euseius* species were conducted and minimal pesticide had been applied compared to those where *Euseius* was not released. *Euseius tularensis* is an effective predator of *P. citri* in southern California orchards during the late winter and spring and in the San Joaquin Valley in spring. *Euseius hibisci* occurs naturally in California citrus and avocado (McMurtry, 1977; Hoddle, 1998), but it is ineffective against heavy web producing *O. perseae,* a major pest on avocado (McMurtry and Johnson, 1965).

A survey of phytoseiids on wild and commercial blackberry plantings in the coastal Santa Cruz and Monterey counties found a notable difference in the number and diversity of phytoseiids (McMurtry & Show, 2012). Nine genera and 12 different species were identified from 19 wild blackberry locations - *P. persimilis, N. californicus*, *N. aurescens* Athias-Henriot, *G. annectans*, *Metaseiulus citri* Garman& McGregor *M. arboreus* Chant, *M. johnsoni* Mahr, *A. similoides* Buchelos and Pritchard, *A. limonicus, T. rhenanoides* Athias-Henriot, *T. eharai*, *E. stipulatus. G. occidentalis* and *M. arboreus* were identified from 12 commercial blackberry locations.

Biological Control

Biological control utilizes a population of natural enemies to manage a pest population (Van Driesche et al., 2008). The idea of using predators in this manner was first discussed in Europe in the 1700s. Rene A. F. Reaumur suggested using green lacewings to manage aphids in greenhouses and Carl Linnaeus described and proposed the use of predatory insects to manage a population of insect pests during a lecture in 1752 (DeBach, 1964).

Interest in natural enemies and confidence in the practice of biological control wavered through to the 20th century (Chant & Fleschner, 1960). Development of organophosphates began in the 1940s and provided the next decade with highly effective chemical pesticides (Bentley et al., 2004; Federighi, 2001). Biological control research and practice faded as a result and pests, including tetranychid spider mites, developed resistance during the 1950s and 1960s with the consistent use of similar pesticides (Huffaker & Flaherty, 1966; van Lenteren, 2003; Jeppson et al., 1975). Tetranychid populations increased as they developed resistance. Phytoseiid populations waned as their phytophagous food sources were subject to routine pesticide applications. Pesticide research found that some pesticide residues persisted in the environment with detrimental effects on non-target organisms including aquatic life (Coppage & Matthews, 1974). Overuse of pesticides and the residual effects led to increased regulations (Federighi, 2001) and the removal of some chemicals from the market. Reduced availability of pesticides, development of resistance among pests and environmental considerations are among the most significant reasons for the upswing in biological control research conducted over the past 40 years (Ridgeway & Inscoe, 1998).

Biological Control Methods

Classical, conservation and augmentation are three major approaches to biological control. Each approach is associated with different methods of implementation and provides either permanent or temporary suppression of pest populations. Biological control methods are applied towards the suppression of mites, insects, vertebrates, weeds and plant pathogens.

Classical Biological Control

Classical biological control has suppressed more than 200 invasive insect species worldwide (Van Driesche et al., 2008). This method provides permanent suppression of non-native invasive pests affecting large, natural urban or outdoor agricultural areas (Van Driesche et al., 2008). Foreign exploration is the practice of studying and collecting the natural enemy that evolved with the target pest in its native region for the purpose of releasing the natural enemy in a different region (Van Driesche et al., 2008). Early uses of the classical control method of importing a predatory insect were recorded in the 1700s in Mauritius. The mynah bird from India was introduced to control the red locust, *Nomadacris septemfasciata,* in 1762 and the predatory pentatomid, *Picromerus bidens*, from Europe to manage bedbugs in 1776 (DeBach, 1964).

Foreign exploration is credited for introducing phytoseiid predators to various regions around the world to manage pest mites on economically important crops. *E. stipulatus* was introduced to California citrus from the Mediterranean region. Natural enemies that evolved with *P. citri* were sought for the purpose of augmenting the existing predator complex in California (McMurtry, 1977). *Euseius stipulatus* was collected from Mediterranean citrus in 1971, it was shipped to and reared in California and it was established in southern California by 1977. *Phytoseiulus persimilis* was reared from both original Chilean stock and individuals collected from Italy to be released and ultimately manage *T. urticae* on strawberry in Ventura County, California (McMurtry et al., 1978). *Phytoseiulus persimilis* became established on strawberry and lima beans and was found to follow resident populations of its preferred host *T. urticae* to weed patches of *Malva*, and *Convolvulus* species when the annual crop was not present. In 1988, *Typhlodromalus* *manihoti* Moraes was introduced to Africa from South America to manage *Mononychellus tanajoa* (Bondar), a pest mite on cassava (Yaninek et al., 1998). The phytoseiid spread throughout a portion of the cassava growing region by 1998, including Benin, Burundi, Ghana and Nigeria, and was recovered from 12 plant species.

Conservation Biological Control

Conservation biological control addresses management practices of the crop and the margins of a production field to attract natural enemies or to maintain and enhance the resident population. Strategies include providing alternate food sources and reducing or eliminating known irritants such as dust or certain chemicals. Conservation practices benefit specific locations where an existing population of natural enemies does not adequately manage pest populations (Van Driesche et al., 2008). These practices often take place in annual cropping systems to improve the management of pests during a given growing season; therefore, suppression is considered temporary. Alternate food sources and refuges are needed after harvesting when cultivation disrupts and displaces natural enemies. Hedge rows or weed strips with a mixture of flowering natives and cultivated plants can provide the needed resources to maintain a complex of predators in the absence of the preferred host (Van Driesche et al., 2008). Windbreaks can reduce wind speeds and reduce the amount of dust that accumulates on leaves. Dust particles can attach to very small parasitoids causing them to stop hunting activities and begin grooming to clean their legs, wings and antennae. Hunting activities do not resume until the irritant has been removed.

Augmentation

Augmentation biological control is the release of mass-produced natural enemies and offers temporary suppression of native or non-native pests for specific areas. Releases can be either inoculative or inundative (Daane et al., 2002; van Lenteren, 2003; Obrycki et al. 1997; Van Driesche et al., 2008). The goal of augmentative releases is to suppress pests for an entire growing season. Inoculative releases introduce small numbers of natural enemies. Inundative releases need to be conducted more often as subsequent generations are not expected to provide adequate control. Rather, it's the released individuals that provide the needed control (van Lenteren, 2003; Van Driesche et al., 2008). Factors that determine usefulness of augmentation programs include availability, quality, and effectiveness of mass-produced natural enemies (Daane et al., 1998; Leppla et al., 2004; Obrycki et al., 1997; Van Driesche et al., 2008; Grenier & De Clercq, 2003).

Commercial Insectaries

The concept of using mass-reared natural enemies was first proposed in Europe in the late 1800s when farming of *Trichogramma* parasites was proposed by F. Enock at the meeting of the London Entomological and Natural History Society (DeBach, 1964).

The market for mass-produced biological control agents is calculated at nearly $350 million (Daar, 1997). More than 125 species of natural enemies are commercially available worldwide for augmentative biological control (Hunter, 1997). Sixty-four commercial insectaries were reported in 1997 – 26 in western Europe, 10 in North America, 8 in central Europe, 5 in Russia, Asia, Australia, and Latin America (van

Lenteren et al., 1997). Agricultural crops in the United States are the largest user of natural enemies with 37% used on trees and vines and 28% used for row and vegetable crops. Other users of biological control include the forestry industry (Ridgway & Inscoe, 1998).

Issues regarding the quality of mass produced arthropods were first addressed in the 1980s (van Lenteren, 1986). The quality of these arthropods affects their ability to exhibit the preferred behaviors upon release in the field after exposure to a laboratory environment. Discussions spurred the development of standards by which to evaluate each species on their rate of development and survival, identity, size and overall behavior (Leppla et al., 2004). Regulatory agencies sought to require proof of identity, purity and efficacy of each reared species. The Association of Natural Bio-Control Producers (ANBP) was established in 1990 to address quality issues, encourage collaborations among its members and to support research and education for the development and use of biological control products. The ANBP represents 40 producers and distributors in the United States, Canada and Europe. The International Biocontrol Manufacturers Association (IBMA), the European counterpart of the ANBP, was established in 1995 and addressed the use of microbial natural enemies, pheromones and other natural products. Leaders from these two organizations collaborated with the International Organization for Biological Control (IOBC) and the Arthropod Mass Rearing and Quality Working Group (AMRQC) to develop quality control guidelines for more than 40 natural enemies (Leppla, et al., 2004).

Quality control guidelines allow users to predict the predator's behavior and efficacy in the field (Leppla et al., 2004). However, not all predator release programs have been scientifically evaluated. A literature review of commercially available predators found 10 predators for which no published literature was found to confirm that these species had been evaluated by means of scientifically conducted field trials (Daane et al., 1998). Less than 5% of the studies that did conduct field trials used commercially recommended release methods. Such evaluations may show a greater reduction in pest densities than can actually be achieved in working operations that do follow the recommended release rates (Daane et al., 1998). Furthermore, some predators were evaluated in environments different from the environment for which it was intended. Predicting a predator's behavior is difficult when these essential elements are modified or absent.

Evaluating potential predators for mass production requires an understanding of its biology (Obrycki et al. 1997) and other characteristics such as feeding and hunting abilities (Daane et al., 1998) in order to use each species effectively. When evaluating biological control agents, it's recommended that the predator's biology is matched with that of the target pest (Daane et al., 1998) and the system for which it is intended (Obrycki et al. 1997). One such complete investigation was conducted on *Amitus bennetti* Viggiani & Evans, a parasitoid of silverleaf whitely, *Bemisia argentifolii* (Joyce et. al., 1999; Joyce & Bellows, 2000; Drost et. al., 1999). These studies comprised a three-part series of publications that included an analysis of the parasitoid's reproductive biology and searching behaviors (Joyce et. al., 1999), a field evaluation (Joyce & Bellows, 2000) and its oviposition behavior and development times (Drost et. al., 1999). *Amitus bennetti* is not commercially available. However, all the necessary information regarding this parasitoid is available should it be needed in the future.

Phytoseiid predators are reared on phytophagous mite prey, natural foods such as pollen, or factitious prey like storage mites. The diet provided depends on the species and host preference and rearing techniques depend on the colony size needed (McMurtry & Scriven, 1965a; Gilkeson, 1992). Some rearing methods are more suitable for producing numbers needed for research colonies. McMurtry and Scriven (1965a) described a rearing unit consisting of a paper substrate and brushing the mites onto microscope cover slips. The cover slips were then transferred to trays and refrigerated. This rearing system produced 1000-2000 predators in 4-6 weeks. More recently, Morales-Ramos & Rojas (2014) proposed a system of stackable plastic cages with spider mite infested lima bean leaves. This stacking system allows the user to add an additional unit and more infested leaves once the spider mites have been depleted. Gravid females were found to remain in the lower levels of the system until oviposition was complete. Subsequently, the female would move up towards the spider mite infested leaves with the rest of the predator population. This rearing system produced approximately 20,000 *P. persimilis*.

Phytoseiulus persimilis can be successfully reared on its preferred host *T. urticae* (Gilkeson, 1992). Eggs and larva of *T. pacificus* has also been used as a host (Scriven & McMurtry, 1971). Rearing phytoseiids on live hosts requires the rearing of the Tetranychid mite and production of their host plant, usually bean. Plants are grown in greenhouses and are inoculated weekly to maintain a continuous supply of tetranychids. The infested plants are then inoculated with phytoseiids and are left on the plant for 2-3 weeks to build up an adequate population. Phytoseiids are then harvested from the bean plant and shipped (Gilkeson, 1992). Rearing *P. persimilis* on *T. pacificus* follows the same steps outlined above for *T. urticae* with additional steps. Instead of inoculating the infested bean plant with phytoseiids, the plant material is rinsed to separate the tetranychids and eggs. The spider mites are dried, weighed and fed to the predators; the eggs are mixed with ground corn cobs, providing a suitable substrate for shipping purposes (Gilkeson, 1992). Vermiculite and coarse wheat bran are also commonly used (Gilkeson, 1992).

Species type III subtype b genera *Amblyseius*, *Amblydromalus*, and *Neoseiulus* have been successfully reared on factitious diets and are commercially available for control of pests in protected crops. Alternate diets are often comprised of grain mites and stored product mites such as *Acarus siro* (Acari: Acaridae), *Carpoglyphus lactis* L. (Acari: Carpoglyphidae), and *Drophagus pulrescenliae* (Acari: Acaridae) (Fidget & Stinson, 2010). *Amblydromalus limonicus* is primarily reared on *C. lactis* L. (Vangansbeke et al., 2014) for control of whitefly and thrips. However, Vangansbeke et al., (2014) found that a diet of a commercial pollen product, *C. lactis* or eggs of the Mediterranean flour moth *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) resulted in a higher rate of population increase than when provided Western flower thrips, *Frankiniella occidentalis* (Pergande) (Thysanoptera: Thripidae).

Neoseiulus cucumeris is used commercially to control thrips and are also reared on stored product mites, such as bran mites. The original method of rearing bran mites described by Ramakers and van Leiburg (1982) introduced the mites to wheat bran in a high humidity environment. The mites would then feed on the fungus that developed on the bran. Adaptations incorporate larger containers, a forced air system to prevent condensation, and improvements in the diet of the grain mites with the addition of yeast (Hansen & Geyti, 1985) wheat germ (Jakobsen, 1989) and a mold mite prey species, *Tyrophagus putrescentiae* (Gilkeson, 1992). The addition of dextrose has been tested and shown to substantially increase the number of lab reared *Amblyseius swirskii* Athias-Henriot (Fidget & Stinson, 2008). *Amblyseius swirskii* is the most widely used commercially available phytoseiid for control of thrips and whitefly (Knapp et al., 2013).

Surveys of Phytoseiids

Phytoseiids are visually similar in size, shape and color; therefore, misidentification commonly occurs during field observations. Positive identification involves examination of the setal patterns of slide mounted adult females with the aid of a compound microscope. Misidentifications can lead to assumptions about a predator's potential and skepticism regarding biological control as a pest management tool. . Identification to genus and species is time-intensive, but it is necessary.

Surveys can lead to descriptions of new species and locate species previously unknown to a particular region, both of which contribute to the development of species distribution maps. McMurtry and Scriven (1965) found and described *E. tularensis* from their survey of California citrus and avocado and determined its preferred region and host plant. Numerous studies have since followed as *E. tularensis* is an important predator in San Joaquin Valley citrus (Grafton-Cardwell & Ouyang, 1995). A survey in Mexico (De Leon, 1961) led to descriptions of 8 new *Amblyseius* species and also noted findings of *A. limonicus* which as only known to exist in the southeastern region of the United States. Identification of key species in a given region helps to minimize subsequent mistakes in reporting and pest management decisions.

Surveys are necessary to understand how laboratory findings translate to field situations. A field survey of avocado orchards in Ventura County was conducted to observe influences of a field environment on *E. hibisci* (McMurtry & Johnson, 1965). The survey confirmed that pollen as a food source does stimulate the reproduction rate in *E. hibisci* independently of tetranychids. Peaks in egg production were associated with flowering and the availability of pollen. Furthermore, *E. hibisci* exploited pollen from trees within the orchard and from pollen blown in from certain neighboring plantings. However, *T. pyri* was only able to successfully reproduce on pollen grains still attached to the anthers as opposed to detached pollen grains that had blown in from other source (Dosse 1961). Such details learned from field surveys clarify species specific capabilities and help to explain the need for further research.

Crops Surveyed

Avocado (Persea americana Mill)

Avocado is an evergreen subtropical tree that was introduced to California from Mexico in 1871. A significant increase in avocado production has occurred over the past 40 years in California: there were 20,000 acres in 1970 (Crane, 1995) and nearly 52,000 acres harvested from San Luis Obispo to San Diego counties (California Avocado Commission). California now produces 90% of all avocados in the US. Frequent flushes of growth occur in warmer regions; one longer flush of growth occurs in cooler regions (California Rare Fruit Growers, 1996a). Flowering occurs March through May, followed by fruit development which lasts through December (Lovatt, 1999). Avocado trees can reach up to 80 feet.

A major mite pest of California avocado is *Oligonychus perseae* Tuttle, Baker and Abbatiello (Acari: Tetranychidae) and *O. punicae* Hirst and *Eotetranychus sexmaculatus* Riley are considered minor pests (Avocado Pest Management Guidelines, 2014). Phytoseiid predators of *O. persea* include *Neoseiulus californicus* McGregor, *Euseius hibisci* Chant, *Galendromus annectans* De Leon, and *G. helveolus* (Avocado Pest Management Guidelines, 2014). Of these, only *N. californicus* is commercially available.

Cherimoya (Annona cherimola Mill.)

Cherimoya is a subtropical, semi-deciduous fruiting tree native to Ecuador and Peru. Seed was first planted in Carpinteria, California in 1871 and is a lesser known specialty crop. California has approximately 200 acres of commercial orchards, mostly in Santa Barbara, Ventura and San Diego counties (Philips et al., 1987). Leaf drop occurs in late April or May followed by bloom that lasts from May through August, peaking in June and July (González et al., 2010). Cherimoya trees grow to 30 feet and fruits ripen October to May (California Rare Fruit Growers, 1996b). Blooming occurs when new leaves are developing and can last for several months. Cherimoya trees grow to 30 feet and fruits ripen October to May (California Rare Fruit Growers, 1996b).

Cherimoya is the only crop included in this survey that is not considered to be significantly impacted by tetranychid mites. No reports were found that identified pest or predator mites that occur on cherimoya and there are currently no pesticides registered for use on cherimoya (California Rare Fruit Growers, 1996b). Cherimoya is a small but growing commodity on the central coast; therefore, pursuing a survey of this crop was deemed important to document the presence or absence of phytoseiids and tetranychids as a basis of information for future use.

Caneberry (Rubus spp.)

Caneberry includes raspberries (subgenus *Idaeobatus*) and blackberries (subgenus *Eubatus*). Hybrids of raspberry and blackberry include loganberry, boysenberry and olallieberry. California planted 5,400 acres of raspberries in 2011 (National Agricultural Statistics Service, 2010). Santa Cruz and Ventura counties are the leading producers of raspberries and Santa Cruz and San Diego counties are the leading producers of boysenberries. Raspberry plants can produce June through October and blackberries are harvested April to October depending on the variety. Boysenberries are harvested between June and July.

Current research notes *Tetranychus urticae* Koch (Acari: Tetranychidae) as a major mite pest of caneberry and *Eotetranychus lewisi* McGregor is identified as a potential pest in Ventura County caneberries (Howell & Daugovish, 2013; Caneberry Pest Management Guidelines, 2014). *Phytoseiulus persimilis* Athias-Henriot is a widely used specialized phytoseiid predator of *T. urticae* (Gilkeson, 1992; Strawberry Pest Management Guidelines, 2010) and initial studies suggest *N. californicus*, *N. fallacis* Garman and *A. andersoni* Chant as possible predators of *E. lewisi* (Howell & Daugovish, 2013).

Grape (Vitis vinifera L.)

California provides 92% of the wine grape production in the US. There are four major grape growing regions in CA – north coast, central coast, Central Valley and the southern valley. The leading varieties produced on the central coast include Cabernet Sauvignon, Merlot, Syrah Chardonnay and Zinfandel (San Luis Obispo County Crop Report, 2011). This growing region has expanded significantly since 1990 when fewer than 20 wineries were reported. By 2011, there were more than 150 wineries in San Luis Obispo County totaling 35,000 acres of wine grapes (San Luis Obispo County Crop Report, 2011).

Eotetranychus willamettei Ewing (Willamette mite) (Acari: Tetranychidae) is a common pest of central coast wine grape; *T. urticae* is considered a minor pest that causes little damage (Grape Pest Management Guidelines, 2014). *Galendromus occidentalis* Nesbitt is named as the most common phytoseiid found in vineyards of the north coast and Central Valley regions (Bentley et al., 2004; Costello, 2007; Grape Pest Management Guidelines, 2014).

Strawberry (*Fragaria X ananassa*)

Strawberry is an annual row crop. California produces 87% of fresh and frozen strawberries in the United States with growing regions extending along the coast from San Diego to Monterey counties. Production in Ventura county peaks in April and harvests in northern Santa Barbara begin in March and continue through July. Strawberries ranked as the 6th most valuable fruit crop in

California (National Agricultural Statistics Service, 2010) and became the most valuable crop, surpassing wine grapes, in San Luis Obispo County in 2011 (San Luis Obispo County Crop Report, 2011).

Tetranychus urticae is a major pest of strawberries and *T. cinnabarinus* Boisduval is considered a minor pest that exists in low densities in cooler temperatures on the central coast (Strawberry Pest Management Guidelines, 2014). Phytoseiids that are commercially available and currently released in strawberries include *P. persimilis, N. californicus, and N fallacis*; *P. persimilis* is the most widely used (Gilkeson, 1992; Strawberry Pest Management Guidelines, 2014).

CHAPTER III

MATERIALS AND METHODS

Sampling Methods for Each Cropping System

A total of 24 field locations were sampled for phytoseiids and tetranychids in 2006 and 2007 (Table 1), with 3 sites in avocado, 3 sites in cherimoya, 5 in caneberry, 6 in grape and 7 in strawberry. Sampling locations crossed three counties (Fig. 1) and a total distance of 176 miles. Leaf samples were collected every two weeks from early spring through fall, or until the crop was no longer available. Leaves were collected from areas of the field with a history of spider mite populations, or from plants along dusty ends of rows from warm shaded areas of the canopy if the pest history was unknown. Field locations that provided an insignificant number of phytoseiids in 2006 were not revisited in 2007 and some locations were replaced with an alternative if they were not available for sampling the second season.

Samples of 100 leaves were intended; fewer leaves were collected from small scale operations. Leaves were collected into paper bags and were transported in a cooler with blue ice packs layered with newspaper on top to minimize the transfer of condensation to the leaf samples. The leaves were returned to the laboratory at Cal Poly State University where the phytoseiids and tetranychids were counted with the aid of a dissecting microscope and a 20x hand lens. The entire lower surface of each leaf was examined. The top surface was inspected when mites sought to avoid the direct light used to count specimens on the underside. Phytoseiids were picked from the leaves with a 5/0 natural hair paint brush and were transferred to prefilled vials of 70% ETOH to be later slide mounted and identified. Tetranychids were site identified only.

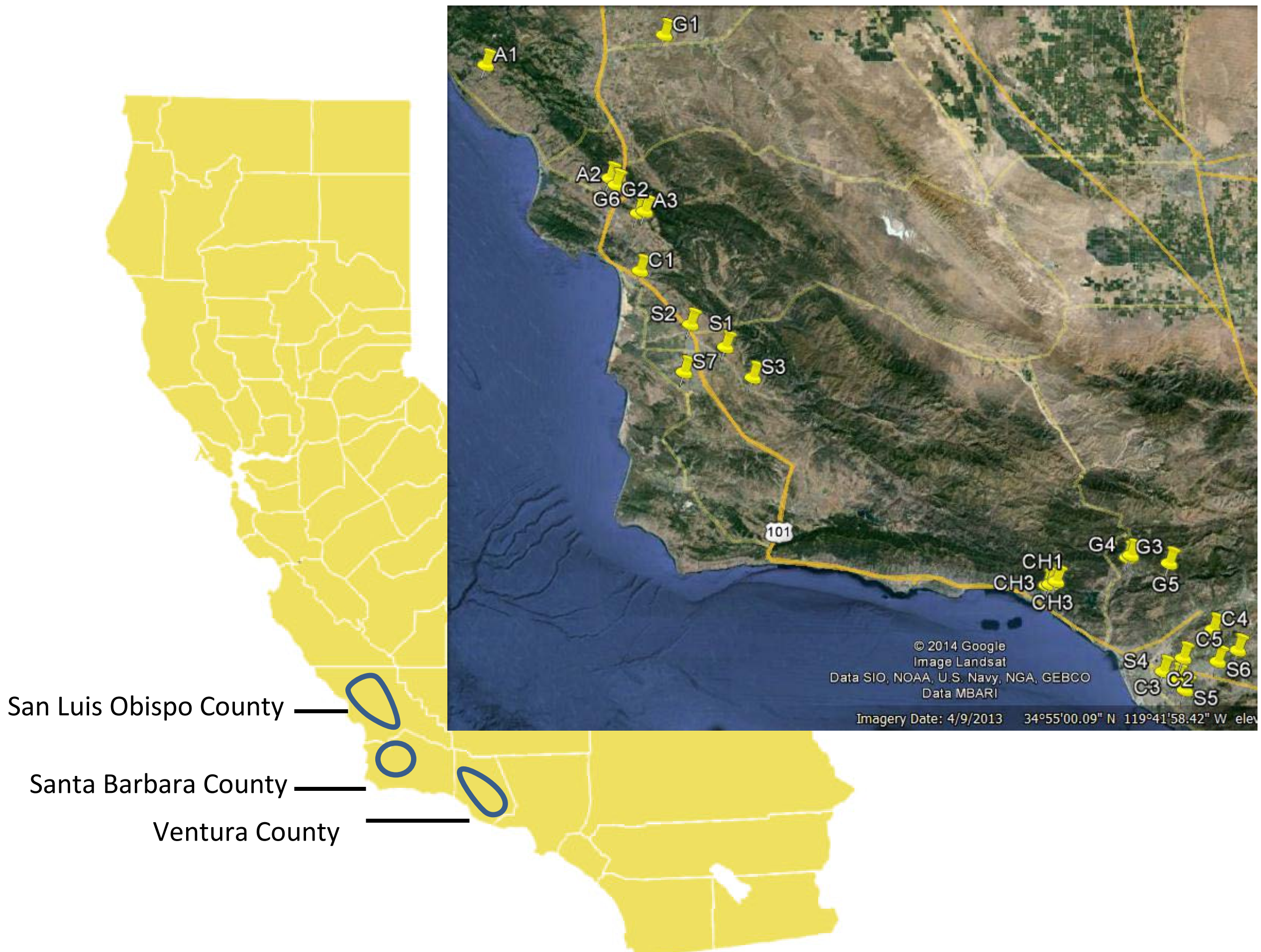

Figure 1. Map of California with location of sampling locations within each county circled. Inset, satellite image of sampling sites.

Table 1. Crops and field locations surveyed.

Crop	Site Name	Location	Variety	Acreage	Date Planted	Key Pests
Avocado						
	A1 – Dos Pasos Ranch	Santa Rosa Creek Rd., Cambria, San Luis Obispo Co., CA	Hass	10	2000	*O. persea*
	A2 – Cal Poly	Highland Ave, San Luis Obispo Co., CA	Hass, Bacon, Fuerte	1.5	1978	*O. persea*, thrips
	A3 – Coyote Canyon Ranch	Coyote Canyon Rd., San Luis Obispo Co. CA	Hass	32.8	1976	*O. persea*
Cherimoya						
	CH1 – Rincon Ranch	Rincon Rd., Carpinteria, Santa Barbara Co., CA	Bays, Dr. White	1.5 ac total	2003	Mealybugs and thrips
	CH2 – Casitas Pass Ranch	Hwy 192, Santa Barbara Co., CA	Bays, Dr. White	6 ac	1999	*Eotetranychus* spp.
	CH3 – Chismahoo Ranch	Chismahoo Trail Rd., Ventura Co., CA	Bays, Dr. White	3 ac	2010	*Eotetranychus* spp.
Caneberry						
	C1a - Rutiz Family Farm	The Pike, Arroyo Grande, San Luis Obispo Co., CA	Raspberry – variety unknown	28 acre farm; 0.27 acres of raspberries	2006	*T. urticae*, *Eotetranychus* spp.
	C1b - Rutiz Family Farm	The Pike, Arroyo Grande, San Luis Obispo Co., CA	Blackberry – variety unknown	28 acre farm; 0.36 acres of blackberries	2005	*T. urticae*, *Eotetranychus* spp.
	C2 – McGrath Ranch	Ventura Blvd., Oxnard, Ventura Co., CA	Holyoke	Not Available	Not Available	*T. urticae*, *Eotetranychus* spp.
	C3 – Pleasant Valley Ranch	Hailes Rd., Oxnard, Ventura Co. CA.	Holyoke	Not Available	Not Available	*T. urticae*, *Eotetranychus* spp.
	C4 – Borchard Ranch	Berylwood Rd., Somis, Ventura Co., CA	Holyoke	Not Available	Not Available	*T. urticae*, *Eotetranychus* spp.
	C5 – Santa Rosa Ranch	Santa Rosa Rd., Somis, Ventura Co., CA	Holyoke	Not Available	Not Available	*T. urticae*, *Eotetranychus* spp.

Table 1. Crops and field locations surveyed, continued.

Crop	Site Name	Location	Variety	Acreage	Date Planted	Key Pests
Grape						
	G1 – Fetzer Five Rivers Ranch	Union Rd., San Luis Obispo Co., CA	Merlot	Not Available	Not Available	Western Grape Leafhopper
	G2 – Pacific Vineyard	Orcutt Rd., San Luis Obispo, San Luis Obispo Co., CA	Chardonnay	200 ac.	Not Available	Willamette mite, *Twospotted spider mite (TSSM)*
	G3 – Ford Vineyard	Quail Oaks Dr., Ojai, Ventura Co., CA	Syrah	0.17 ac.	2000	None
	G4 – Chief Peak Vineyard	France Circle, Ojai, Ventura Co., CA	Syrah	2 ac.	Not Available	Willamette mite
	G5 – Roll Ranch	Santa Paula Rd., Ojai, Ventura Co., CA	Syrah	6 ac.	Not Available	Willamette mite
	G6 – Trestle Vineyard, Cal Poly State University	Stenner Creek Rd., San Luis Obispo, San Luis Obispo Co., CA	Chardonnay	14 ac.	Not Available	Willamette mite
Strawberry						
	S1 – Betteravia Ranch	E. Betteravia Rd., Santa Maria, Santa Barbara Co., CA	Not Available	Not Available	Not Available	TSSM
	S2a – Donavan Ranch	Blosser Rd., Santa Maria, Santa Barbara Co., CA	Not Available	Not Available	Not Available	TSSM
	S2b – Donavan Organic Ranch	Blosser Rd., Santa Maria, Santa Barbara Co., CA	Not Available	Not Available	Not Available	TSSM
	S3 – Sisquoc Field	Foxen Canyon Rd., Sisquoc, Santa Barbara Co., CA	Not Available	Not Available	Not Available	TSSM
	S4 – Donlon Ranch	Wooley Rd., Oxnard, Ventura Co., CA	Not Available	Not Available	Not Available	TSSM
	S5 – Davis Ranch	Hueneme Rd., Oxnard, Ventura Co., CA	Not Available	Not Available	Not Available	TSSM
	S6 – Sammis Ranch	Pleasant Valley Rd., Camarillo, Ventura Co., CA	Not Available	Not Available	Not Available	TSSM
	S7 – Eraud Farms	Hwy 1, Orcutt, Santa Barbara Co., CA	Albion	160.7	Not Available	TSSM

Avocado

Three avocado orchards in San Luis Obispo County were surveyed. Leaves were collected every two weeks from March through October for a total of 16 sample dates in 2006. The sampling frequency was reduced to once a month in 2007. Consistent findings of the same phytoseiid species in 2006 led to the decision to reduce the sampling frequency. Sampling occurred between April and October for a total of 7 sampling dates in 2007. Leaf samples consisted of 5 leaves from 20 trees for a total of 100 leaves at each orchard. Fully expanded mature leaves were selected from warm shaded areas of the canopy both seasons.

Abamectin and Omni oil were applied at each orchard targeting *O. perseae* and avocado thrips (*Scirtothrips perseae)* (Table 2). Application information was not available for site A3-2007.

Table 2. Pesticide applications for avocado, 2006 and 2007.

Location/Yr	Formulation	Chemical Name	Target Pest	Rate of Application/Acre	Date
A1-2006	Agri-Mek 0.15 EC	Abamectin	Persea mites	7.2 oz.	June 14
	Omni Oil 6E	Mineral oil	Persea mites, Avocado thrips	1.6 gal.	June 14
A1-2007	Epi-Mek 0.15 EC	Abamectin	Persea mites	10 oz.	June 11
	Omni Oil 6E	Mineral oil	Persea mites, Avocado thrips	1.7 gal.	
A2-2006	Omni Oil 6E	Mineral oil	Persea mites, Avocado thrips	8.6 gal.	Sept 26
	Omni Oil 6E	Mineral oil	Persea mites, Avocado thrips	1 gal.	Sept 30
A2-2007	Agri-Mek 0.15 EC	Abamectin	Persea mites	33 oz.	June 19
	Omni Oil 6E	Mineral oil	Persea mites, Avocado thrips	12 gal.	
A3-2006	Agri-Mek 0.15 EC	Abamectin	Persea mites	Not Available	July 17
	Omni Oil 6E	Mineral oil	Persea mites, Avocado thrips	Not Available	July 17
A3-2007	Not Available	----	----	----	----

Site A1: Dos Pasos Ranch

35°34'31.86"N, 121° 2'16.96"W; elevation: 67.4 m.

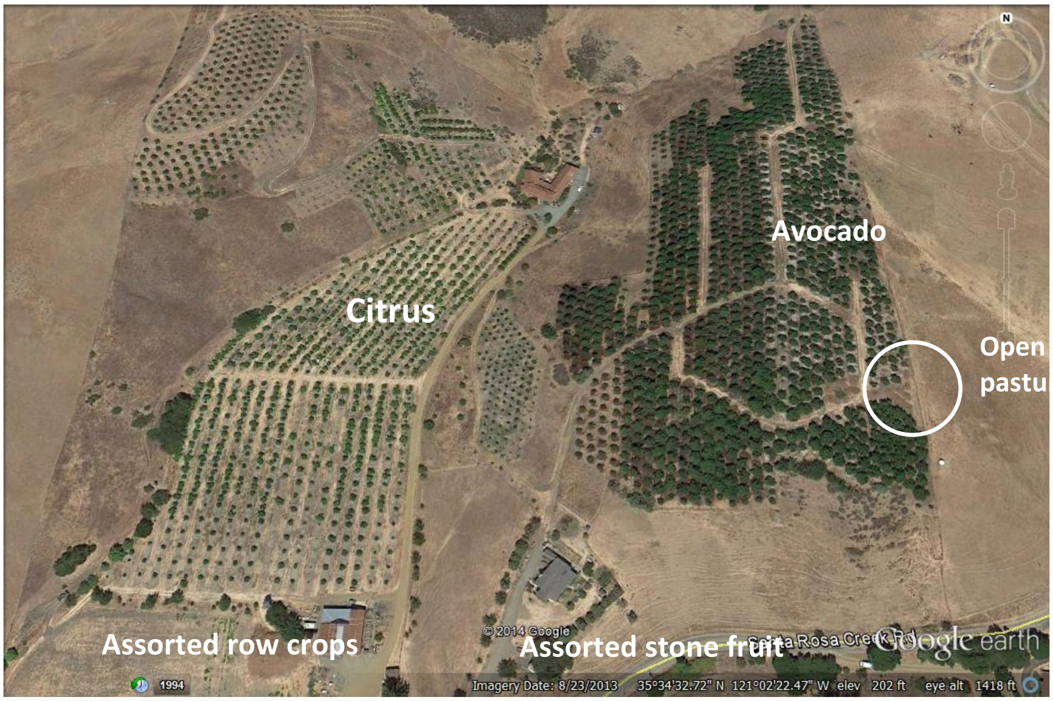

Figure 2. Site A1 with sampled area circled and surrounding crops and vegetation labeled.

Site A1 had citrus, Hass avocado, and smaller plantings of seasonal crops (Fig. 2). The entrance of the ranch was planted with a variety of fruit trees, vegetables, pumpkins, squash and gourds. The major structures on the property included a barn, a guest home and the main residence.

Avocado thrips was the insect pest of greatest concern to the grower and it was found in June and July both seasons on 7 or fewer leaves of the 100 leaf sample. Agri-Mek (7.2 oz./ac) and Omni Oil (1.6 oz./ac) were applied on June 14 in 2006 and on June

11 in 2007 for control of avocado thrips (Table 2). Site A1 was maintained by the property owners and one employee.

Leaf Samples

The sampling location recommended by the property owner was a low lying section of the orchard that was typically a few degrees warmer than the rest of the orchard and had developed pest mite populations during prior seasons. Leaves were collected between 1000 and 1140 in 2006 and the average temperature was 16.67˚C; between 0815 and 0915 in 2007 with an average temperature of 59.6˚C.

Site A2: Cal Poly Avocado Orchard

35°18'3.52"N, 120°40'1.40"W; elevation: 87.5 m.

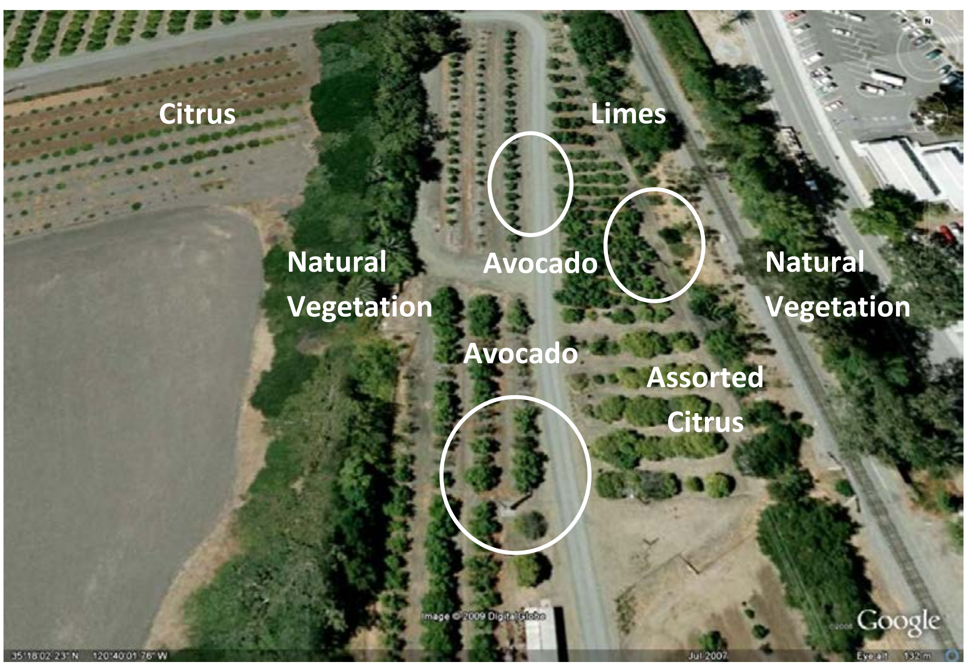

Figure 3. Site A2 with sampled areas circled and surrounding crops and vegetation labeled.

Site A2 was a Hass orchard with a mixture of older trees scheduled to be removed and newer plantings less than two years old. The orchard was near citrus and a stand of natural vegetation that lined a seasonal creek.

Omni Oil was applied on September 26, 2006, at a rate of 8.6 gal/ac (Table 2). A follow up application, 1 gal/ac, was applied four days later on September 30 to control persea mites and avocado thrips. Agri-Mek (33 oz./ac.) and Omni Oil (12 gal.) were applied on June 19 in 2007 to control persea mites and avocado thrips (Table 2). This orchard was managed by University staff including an orchard manager, a certified Pest Control Advisor and student workers.

Leaf Samples

No particular area of this orchard was known to develop pest mite populations (P. DeCarli, personal communication, March 22, 2006). Trees were sampled along dusty ends of rows and trees were selected while searching for signs of pests and predatory mites in warm shaded pockets of the orchard. Samples were collected between 0845 and 1330 and the average temperature was 20.0˚C in 2006; between 0815 and 0915 with an average temperature of 15.55˚C in 2007.

Site A3: Coyote Canyon Ranch

35˚14’27”N, 120°35'7.36"W; elevation: 171 m.

Figure 4. Site A3 with sampled areas circled and location of nearby citrus labeled.

Site A3 was located two miles east of Orcutt Road in San Luis Obispo. The majority of the ranch was planted with avocados except for a small planting of citrus that lined a fence near the property entrance. This orchard suffered frost damage in 2006 which resulted in fruit drop. Damaged limbs were pruned (J. Ramsgard, personal communication, May 21, 2007) and new growth was visible in April when sampling began.

Oligonychus persea was the major pest present in this orchard. Agri-Mek and Omni Oil were applied on July 17, 2006 for control of persea mites and avocado thrips

(Table 2); application rates were not available. Insecticide information was not available for 2007. Other pests present included citrus whitefly *(Dialeurodes citri*), Western spotted cucumber beetle (*Diabrotica undecimpunctata*), and brown soft scale (*Coccus hesperidum*) all of which were located on three separate sampling dates and numbered fewer than 12 individuals on 10 or fewer leaves per 100 leaf sample. This orchard was managed by a work crew and a certified pest control advisor.

Leaf Samples

The sampled area was along the low lying perimeter of the orchard that developed a pest mite population during prior seasons (J. Ramsgard, personal communication, March 22, 2006). Leaf samples were gathered between 0830 and 1300 and the average temperature was 20.55˚C in 2006; between 0930 and 1220 with an average temperature of 17.22˚C in 2007.

Cherimoya

Three cherimoya orchards were surveyed - two in southern Santa Barbara County and the third bordered the Ventura and Santa Barbara County line. All three orchards were managed by the same supervisor and received similar maintenance. The trees were topped or thinned in late April or May in 2006 and 2007 and no pesticides or fertilizers were applied (S. Van Der Kar, personal communication, November 2, 2007).

Leaf samples were collected between March and November for 12-14 sampling dates in 2006. The second sampling date in September for all three locations was cancelled due to the Day Fire that began September 4 in the Los Padres National Forest and burned for one month. The sampling frequency changed from twice a month in 2006 to once a month in 2007. Consistent findings of the same phytoseiid species in 2006 led to the decision to reduce the sampling frequency. Leaves were collected between April and October in 2007 for a total of 7 sampling dates.

The majority of tetranychids were found on medium size leaves, 5 – 7 inches in length, and phytosiids were found mostly on smaller leaves, less than 5 inches in length. The tendency was to sample from trees that were likely to have phytoseiids, from locations within the canopy preferred by phytoseiids and from small to medium size leaves. Leaf samples were selected from shaded areas of the canopy when possible.

Site CH 1: Rincon Ranch

34°23'15.91"N, 119°28'30.23"W elevation: 79 m

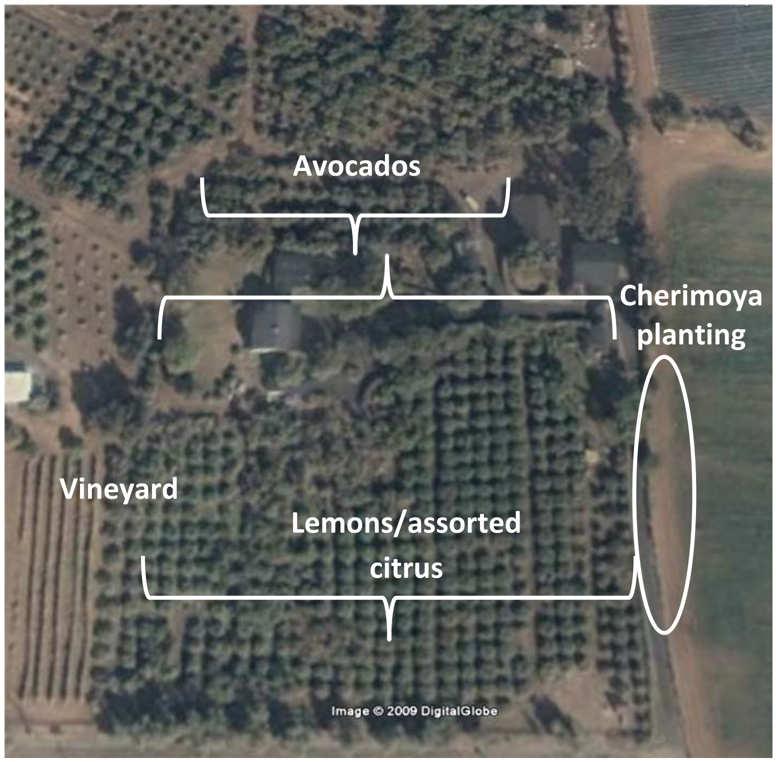

Figure 5. Site CH 1 with sampled cherimoya circled and location of surrounding vineyard, lemon and avocado orchards marked.

Site CH1 was a private residence located off Highway 150 near the south end of Santa Barbara County. Much of the property was planted with citrus and garden vegetables near the cherimoya trees (Fig. 5). This small planting of 32 cherimoya trees was situated between lemon trees and a fence that ran along the private entrance road.

Leaf Samples

Leaf samples consisted of 5 leaves from 5 trees for a total of 25 leaves due to the small size of this orchard. Samples were gathered from 0845 and 1045 and the average temperature was 21.6˚C in 2006; between 0945 and 1100 with an average temperature of 21˚C in 2007.

Site CH2: Casitas Pass

34˚23’26”N, 119˚27’54”W; elevation 83 m

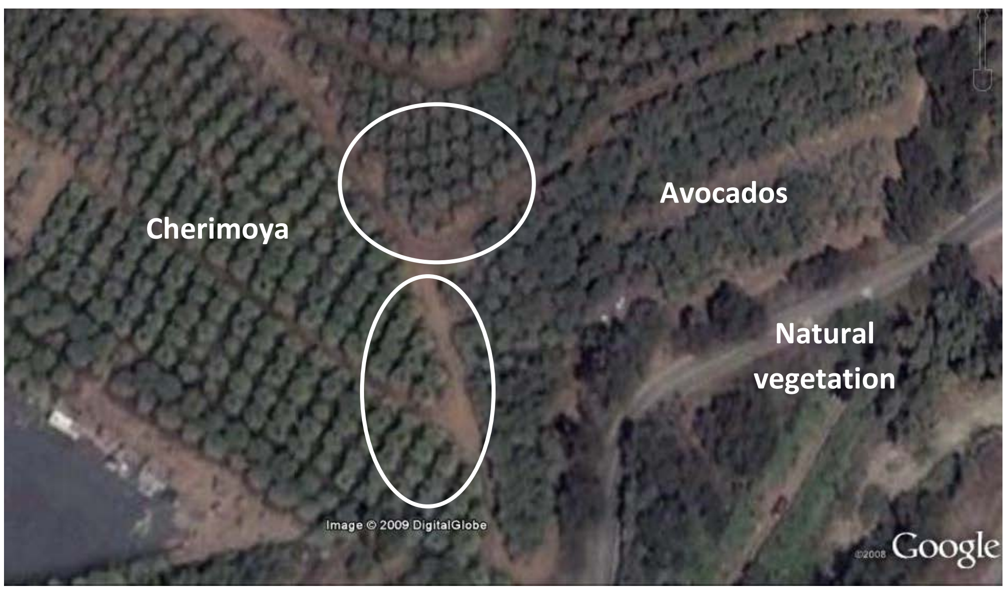

Figure 6. Site CH2 with location of sampled cherimoya circled and surrounding avocado and vegetation labeled.

Site CH2 was located on highway 192 near the Santa Barbara and Ventura County line. The majority of the orchard was planted with avocados (Fig. 6). Natural vegetation lined the perimeter of the property.

Leaf Samples

Leaf samples consisted of 5 leaves from 10 trees for a total of 50 leaves. Samples were gathered between 0915 and 1140 and the average temperature was 22.7˚C in 2006; between 1000 and 1135 with an average temperature of 21.6˚C in 2007. Road construction caused the cancellation of two sample dates, May 31 and July 11, in addition to the September cancellation caused by the Day Fire.

Site CH3: Chismahoo Ranch

34˚23'50"N, 119˚26'57"W; elevation 130m

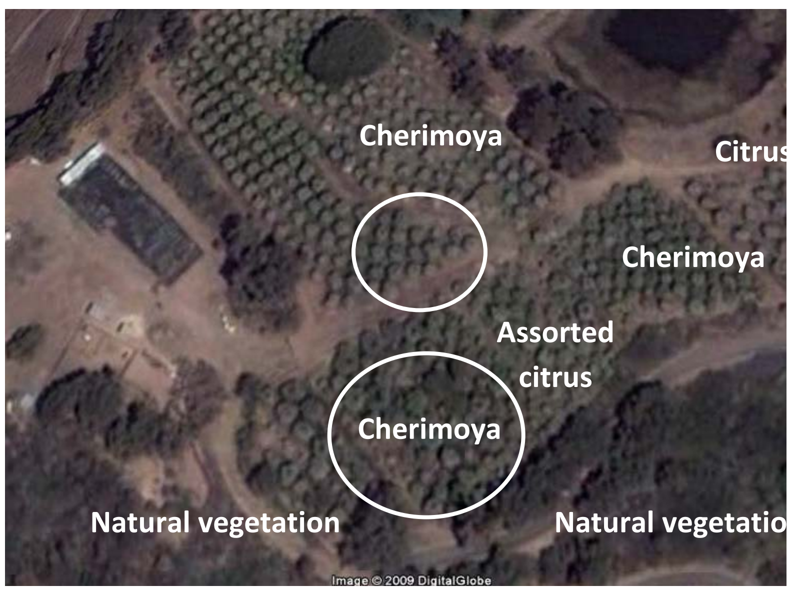

Figure 7. Site CH3 with location of sampled cherimoya circled and location of surrounding citrus and vegetation labeled.

Site CH3 was located on a narrow winding road off highway 150. This was a working ranch with animals, cacti, and natural vegetation on the property (Fig. 7). Assorted citrus was interplanted among the cherimoya.

Leaf Samples

Leaf samples consisted of 5 leaves from 10 trees for a total of 50 leaves. Leaves were collected between 0930 and 1215 and the average temperature was 23˚C in 2006; between 1030 and 1200 with an average temperature of 21.9˚C in 2007.

Caneberry

Five caneberry field sites were sampled in Ventura and San Luis Obispo County (Table 1). Site C1 was the only site with both raspberries and blackberries. Leaf samples were collected between March 30 and October 25 for a total of 10-14 sample dates. Samples consisted of 25 leaves from 4 rows for a total of 100 leaves from all but one site. Site C1 samples consisted of 5 leaves from 10 raspberry plants and 10 blackberry plants for a site total of 100 leaves. Leaves were collected from sections of the vine most likely to acquire mite populations - the lower 0.5 m of the vine and the middle section, approximately 1m high (Personal communication, P. Phillips, March, 2006).

Pesticide information was only available for site C1 which did not apply any pesticides. Each field conducted augmentative releases of *P. persimilis*; however, not all dates and release rates were available.

Table 3. *Phytoseiulus persimilis* releases in caneberry, 2006 and 2007.

Location	Species	Rate of Release/acre	No. of Releases	Date of Release
C1	*P. persimilis*	~3,000/ac	One	June 23, 2006
C1	*P. persimilis*	~3,000/ac	One	August 8, 2006
C2	Not Available	----	----	2006
C3	Not Available	----	----	2006
C4	Not Available	----	----	2006
C5	Not Available	----	----	2006
C1	None	----	----	2007
C3	*P. persimilis*	~20,000/ac	Not Available	May 10, 2007
C4	*P. persimilis*	~20,000/ac	Not Available	May 10, 2007
C5	Not Available	----	----	2007

Site C1: Rutiz Family Farm

35° 6'17.58"N, 120°35'51"W; elevation: 21 m.

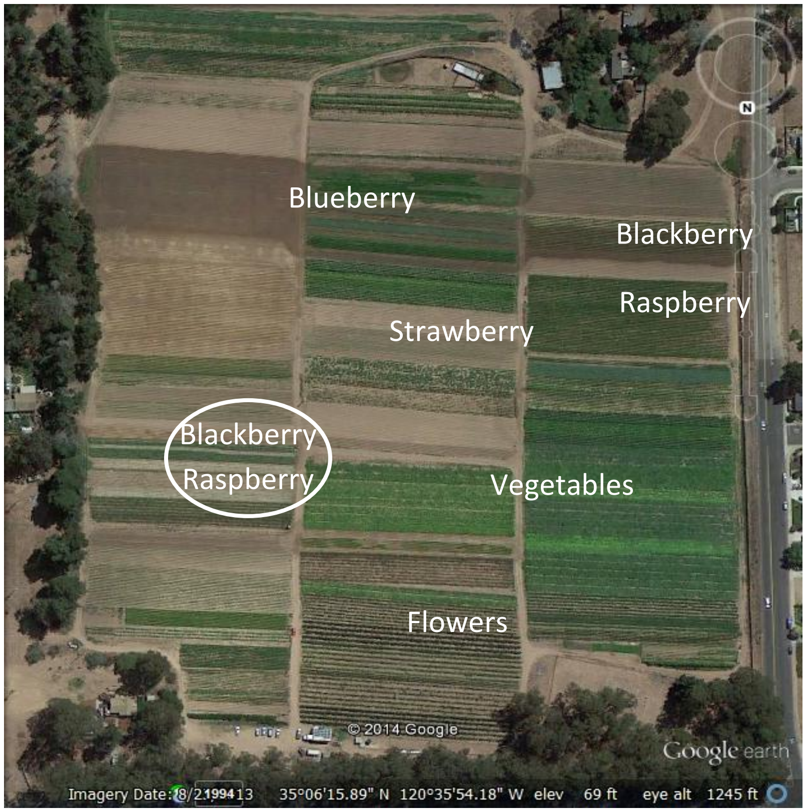

Figure 8. Site C1 with location of sampled caneberry rows circled and location of surrounding crops labeled.

Site C1 featured multiple crops including raspberries, blackberries, strawberries, blueberries and a continuous rotation of vegetables and cut flowers (Fig. 8). The caneberry plantings were small, consisting of 7 rows of blackberries and 9 rows of raspberries, all of which were thornless varieties. This farm was managed by the owner and a small work crew.

Phytoseiulus persimilis were released by the work crew in June and August 2006 in the strawberry and caneberry plantings (Table 3). A variety of insect pests and beneficial predators were observed during both seasons. However, rust was prevalent on the caneberries and was particularly heavy on blackberry in 2006. No pesticides or herbicides were applied at site C1.

Leaf samples

Leaves were collected every two weeks except in May when late rains caused the cancellation of one sampling date. The ends of rows where dust would typically collect were searched first. However, the soil at site C1 was extremely sandy and the leaves were mostly gritty as opposed to dusty. Leaves were collected between 0825 and 1440 and the average temperature was 17˚C in 2006; between 0900 and 1130 with an average temperature of 17.7˚C in 2007. Raspberry and blackberry sampling data were recorded separately.

The raspberry plants were newly planted in March when sampling began; therefore leaves were collected beginning in June. Pest mite hot spots did not develop in 2006. Rather, individuals were located throughout the planting. The heaviest pest mite colonies on blackberry were concentrated near the middle of the rows.

Site C2: McGrath Ranch

34°13'12"N, 119° 6'9.3"W; elevation 18 m.

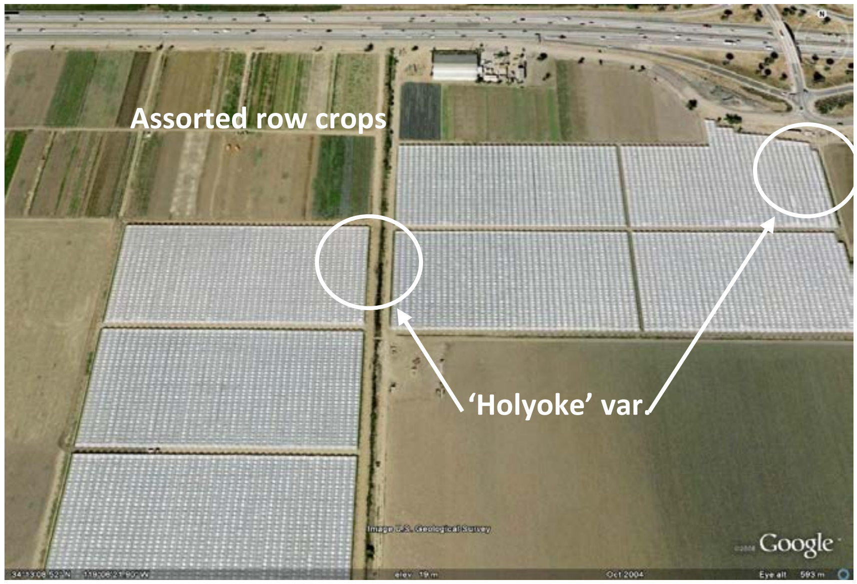

Figure 9. Site C2 with location of sampled 'Holyoke' var. circled and location of nearby row crops labeled.

Site C2 was located between the 101 freeway and the Camarillo Airport. Organic raspberries at this location were housed under open-ended plastic hoops (Fig. 9). This property also produced a mix of row crops. Site C2 was maintained by one manager, a certified pest control advisor and a work crew that handled harvest, biological control releases and other maintenance activities.

Leaf Samples

Two blocks of the 'Holyoke' variety were sampled. Leaf samples were collected between 0900 and 1040 and the average temperature was 18.9˚C. The fewest number of phytoseiids and tetranychids were located at this location and sampling did not continue in 2007.

Site C3: Pleasant Valley Ranch

34˚10'1"N, 119˚7'21"W; elevation 8.5 m.

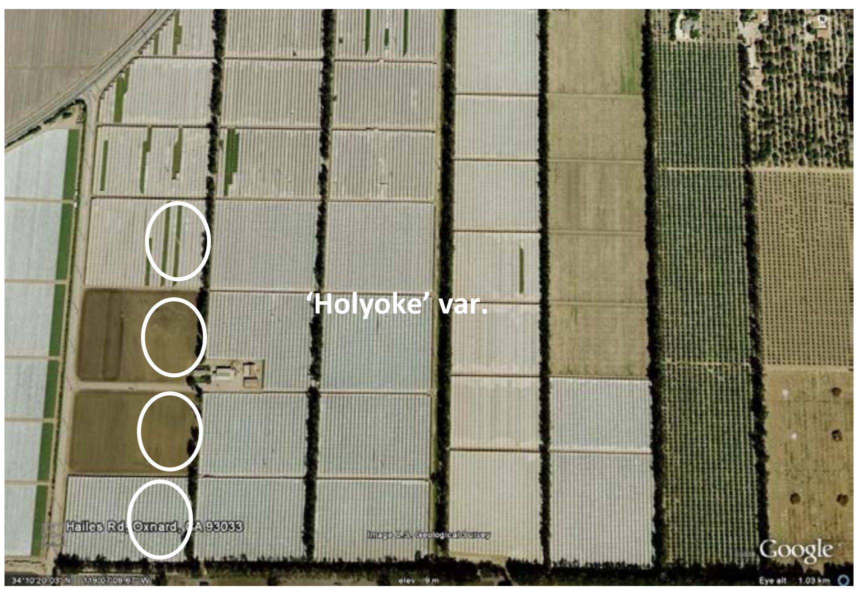

Figure 10. Site C3 with location of sampled 'Holyoke' var. circled.

Site C3 was located east of Oxnard city limits and produced organic raspberries housed under open-ended plastic hoops (Fig. 10). The ranch was maintained by one manager, a certified pest control advisor and a work crew that handled harvest, biological control releases and other maintenance activities. *Phytoseiulus persimilis* were released by the work crew in May 2007.

Leaf Samples

The 'Holyoke' variety was selected for sampling due to the susceptibility of this variety to spider mites (M. Magdaleno, personal communication, March 6, 2006). These vines reached 1.5-1.8 meters by the end of August and were harvested in early September, 2006. The vines were removed by the middle of May and an alternate section of 'Holyoke' var. was sampled for the remainder of the season. The vines in the alternate block began to decline in August. Samples were collected between 0900 and 1300 and the average temperature was 20˚C in 2006; between 1025 and 1320 an average temperature of 18.8˚C in 2007.

Site C4: Borchard Ranch

34˚17’7”N, 119˚1’13”; elevation 160 m.

Figure 11. Site C4 with location of sampled Holyoke’ var. circled.

Site C4 was located in the eastern portion of Ventura County and produced organic raspberries housed under open-ended plastic hoops (Fig. 11). This ranch was maintained by one manager, a certified pest control advisor and a work crew. *Phytoseiulus persimilis* were released by the work crew in May 2007.

Leaf Samples

One block of ‘Holyoke’ var. was sampled. These vines were harvested and began to decline by July 18; however, the vines were not removed in 2006. In 2007, the vines grew to 1.5-1.8 m tall and flowered and set fruit by April. The block was harvested and the vines began to decline in June, at which point sampling was suspended. Leaf samples were collected between 1000 and1430 and the average temperature was 20˚C in 2006; between 1140 and 1300 with an average temperature of 18.9˚C in 2007.

Site C5: Santa Rosa Ranch

34˚14"14'N, 118˚57"11'W; elevation 70.7 m.

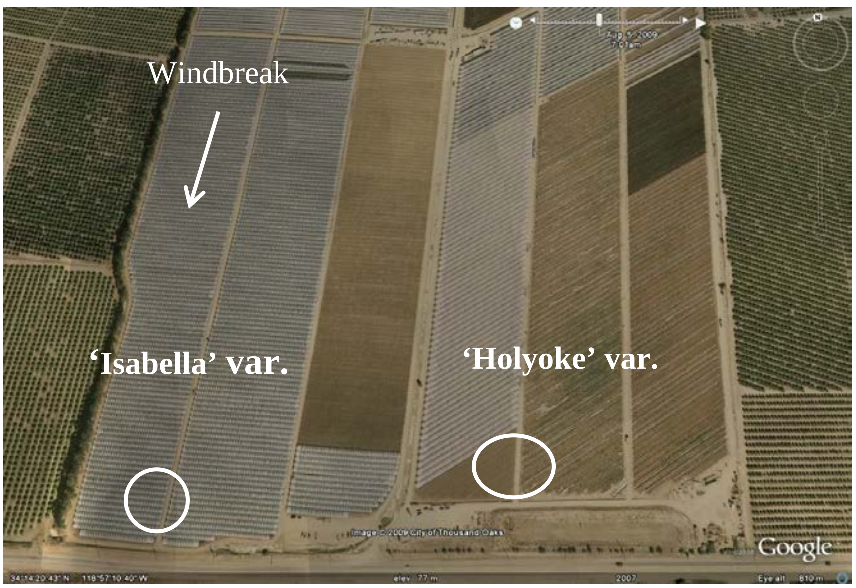

Figure 12. Site C5 with the location of sampled 'Isabella' and 'Holyoke' varieties circled.

Site C5 produced conventionally grown raspberries located along a highway in Somis, just south of Camarillo. The field was partially protected from wind by a eucalyptus windbreak on the north side of the property (Fig. 12). This location was maintained by a manager, and a certified pest control advisor and a work crew. Methyl bromide and chloropicrin were applied to the soil before new canes were planted. Bee hives were kept on site near the entrance of the property.

Leaf Samples

The ‘Isabella’ variety is susceptible to spider mites (M. Magdaleno, personal communication, March 6, 2006) and was sampled at the beginning of the season. The vines began to decline in July and were removed by the next sampling date. A block of ‘Holyoke’ was selected as an alternate and was sampled for the remainder of the season. This block was harvested in September and began to decline soon thereafter. Light pruning took place and new growth emerged two weeks later. The same block of ‘Holyoke’ var. was sampled in 2007. The vines in this block were removed in August and an alternate block was not selected. Leaf samples were collected between 1130 and 1330 and the average temperature was 22.8˚C in 2006; between 1215 and 1330 with an average temperature of 18.9˚C in 2007.

Grape

Six vineyards in San Luis Obispo County and Ventura County were surveyed. These vineyards varied in size ranging from less than 384 vines to 200 acres. Leaf samples were collected between May and October for 10-13 sample dates. The sample size was adjusted depending on the size of the vineyard. The plants sampled were located near the end of rows near dusty roads and pathways or from areas recommended by the vineyard manager. Fully expanded leaves were selected from shaded parts of the vine canopy when possible.

Insecticide information was not available for sites G1, G3, G4 or G5.

Site G1: Fetzer Five Rivers Ranch

35˚38’42”N.120˚32’6”W; elevation: 347m

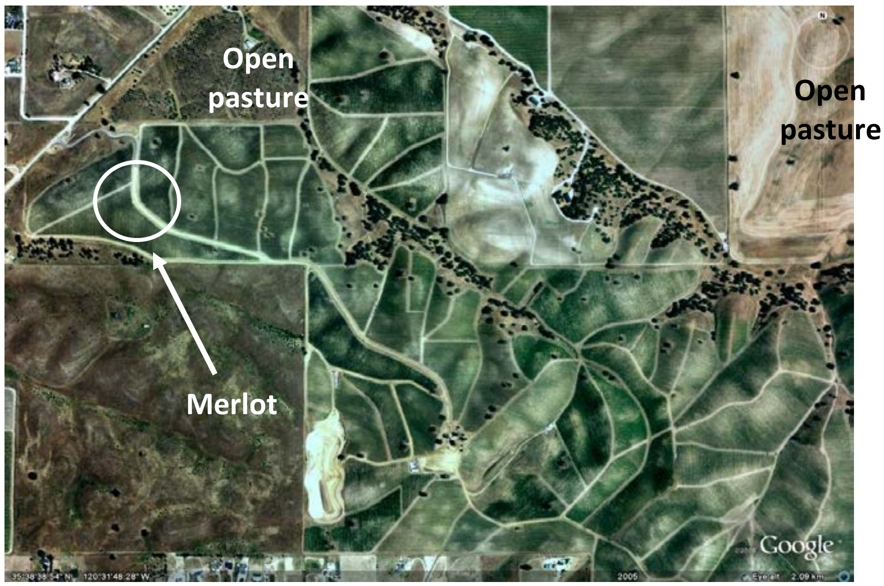

Figure 13. Site G1 with location of the sampled block of Merlot circled and location of nearby open pastures labeled.

Site G1 was a certified organic vineyard located near Hwy 46 in the northern section of San Luis Obispo County. Natural vegetation lined a portion of the perimeter and a center section of the vineyard (Fig. 56). This vineyard was maintained by one manager, a certified pest control advisor and a large work crew.

Leaf Samples

The Merlot variety was selected for sampling due to its history of pest mites (W. Roddick, personal communications, April 30, 2006). Samples consisted of 5 leaves from 20 vines for a total of 100 leaves. Leaves were collected between 0745 and 0945 and the average temperature was 15.5˚C in 2006. Phytoseiids were not located in this vineyard in 2006 and sampling did not continue in 2007.

Site G2: Pacific Vineyard

35°14'11.00"N, 120°36'13"W; elevation: 110m

Figure 14. Site G2 with Chardonnay blocks labeled and brackets indicating sampled vines. Neighboring vineyard operations are labeled.

Site G2 was a 200 acre planting located in the southern end of San Luis Obispo city limits (Fig. 14). This vineyard was managed by a production manager, an in-house certified pest control advisor and a large work crew. Lorsban 4E was applied in February, 2006, before sampling began (Table 4). Multiple applications of stylet oil and sulfur were applied for powdery mildew and obscure mealybug (*Pseudococcus viburni*) in June and July, 2006. Stylet Oil, Applaud 70DF, Quintec, Microthiol Disperss, and Venom insecticides were applied in 2007.

Table 4. Insecticide applications for site G2, 2006 and 2007.

Location/Yr	Formulation	Chemical Name	Target Pest	Application Rate/Acre	Date
G2-2006	Lorsban 4E	Chlorpyrifos	Obscure mealybug	2.0 qt.	Feb 9
	Stylet-Oil	Paraffinic oil	Willamette mite, TSSM, Obscure mealybug	0.67 gal.	May 6
	Stylet-Oil	Paraffinic oil	Willamette mite, Obscure mealybug	1.0 gal.	May 18
	Spray Sulfur	Sulfur	Powdery mildew	4.10 lb.	June 8
	Spray Sulfur	Sulfur	Powdery mildew	1.97 lb.	June 23
	Spray Sulfur	Sulfur	Powdery mildew	1.94 lb.	June 30
	Spray Sulfur	Sulfur	Powdery mildew	2.02 lb.	July 7
	Spray Sulfur	Sulfur	Powdery mildew	1.99 lb.	July 15
	Spray Sulfur	Sulfur	Powdery mildew	2.00 lb.	July 24
	Spray Sulfur	Sulfur	Powdery mildew	2.00 lb.	July 28
G2-2007	Stylet-Oil	Paraffinic oil	Willamette mite, Obscure mealybug	3.13 qt.	April 18
	Stylet-Oil	Paraffinic oil	Willamette mite, Obscure mealybug	3.13 qt.	May 11
	Applaud 70DF	Buprofezin (16)	Willamette mite	12.25 oz.	May 25
	Quintec	Quinoxyfen (13)F	Powdery mildew	6.12 oz.	May 25
	Microthiol Disperss	Sulfur	Powdery mildew	3.01 lb.	June 9
	Venom Insecticide	Dinotefuran(4A)	Grape leafhopper, Obscure mealybug	6.00 oz.	June 16
	Microthiol Disperss	Sulfur	Powdery mildew	2.00 lb.	June 23
	Applaud 70DF	Buprofezin	Grape leafhopper, Obscure mealybug	12.12 oz.	July 7
	Microthiol Disperss	Sulfur	Powdery mildew	2.02 lb.	July 7
	Microthiol Disperss	Sulfur	Powdery mildew	2.03 lb.	July 21

Leaf Samples

The Chardonnay variety was selected for sampling as it had developed pest mite populations during previous seasons (E. Amaral, personal communication, March 26, 2006). Leaf samples consisted of 5 leaves from 20 vines for a total of 100 leaves. Samples were collected between 1215 and 1345 and the average temperature was 21˚C in 2006; between 0920 and 1100 and the average temperature was 17.7˚C.

Site G3: Ford Vineyard

34˚27’4”N, 119˚15’14”W; elevation: 252m

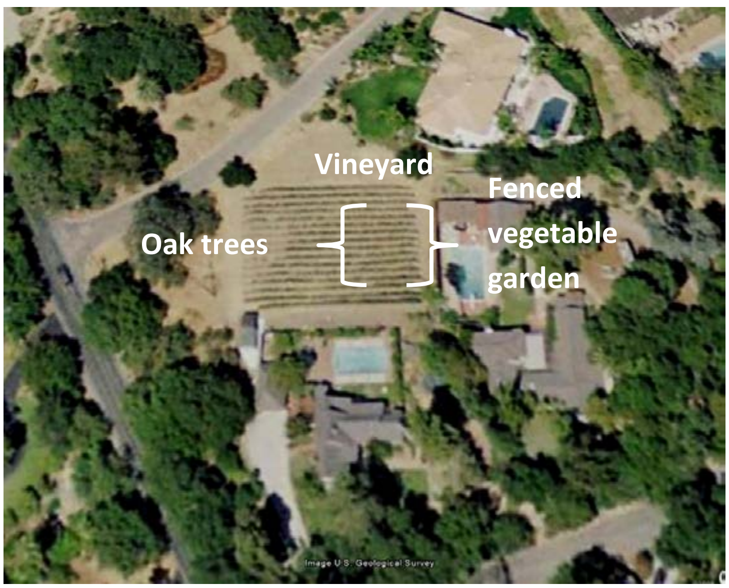

Figure 15. Site G3 with brackets indicating sampled vines and location of surrounding oaks labeled.

Site G3 was located in the backyard of a private residence (Fig. 15). This small vineyard consisted of 16 rows of 24 vines and was maintained largely by one vineyard manager. Minor weeding and pruning was handled by the property owner. The vineyard floor was kept clean and the vines were trimmed with hand pruners on July 11, 2006.

Leaf Samples

Leaf samples consisted of 5 leaves from 5 vines for a total of 25 leaves. Samples were collected between 1100 and 1315 and the average temperature was 23.6˚C in 2006. The fewest number of phytoseiids were located at this vineyard and sampling did not continue in 2007.

Site G4: Chief Peak Vineyard

34˚27’22”N, 119˚14’41”W; elevation: 224m

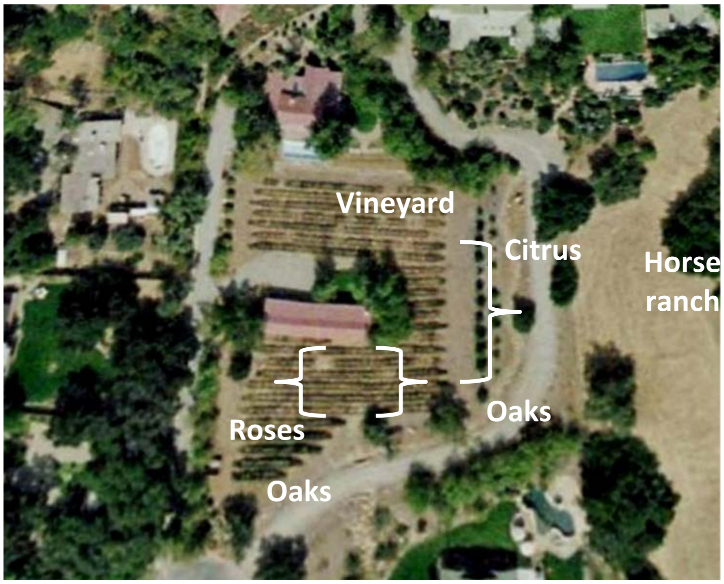

Figure 16. Site G4 with brackets indicating sampled vines. Surrounding plantings and neighboring ranch labeled.

Site G4 was located on the property of a private residence that included oaks, citrus and roses (Fig. 16). This property was maintained by one vineyard manager and a small work crew. The vines were not pruned and were long and bushy. Weeds were minimal.

Leaf Samples

Leaf samples consisted of 5 leaves from 10 vines for a total of 50 leaves. Samples were collected between 1145 and 1415 and the average temperature was 23.6˚C in 2006; between 1125 and 1400 with an average temperature of 28.8˚C in 2007.

Site G5: Roll Ranch

34˚26’14”N, 119˚08’23”W; elevation: 475m

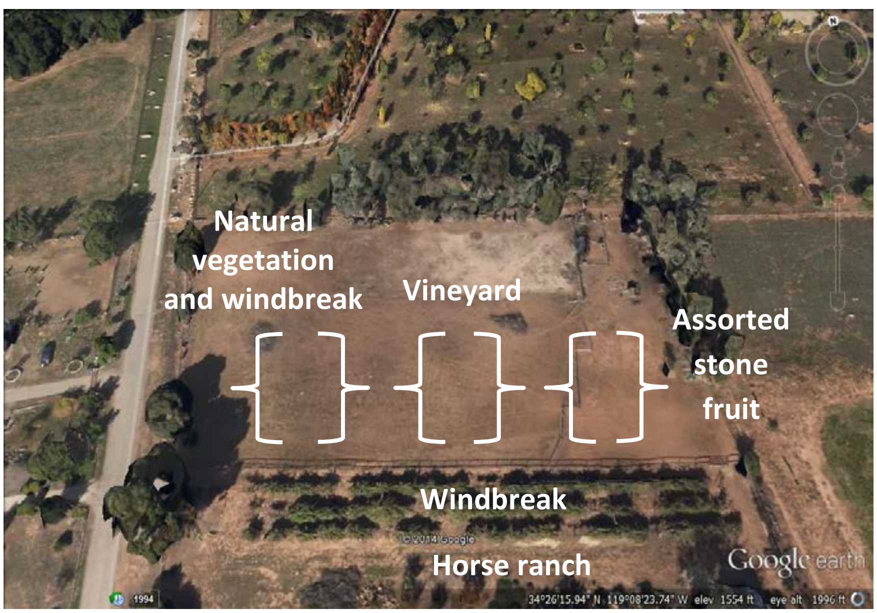

Figure 17. Site G5 with brackets indicating sampled areas and surrounding vegetation, plantings, windbreaks, and neighboring ranch labeled.

Site G5 was located behind a horse ranch along Hwy 150 between Ojai and Santa Paula. The surrounding vegetation included oak trees, pine trees and young stone fruit trees (Fig. 17). This site was maintained by one manager and a work crew. These vines grew to a density thicker than those at site G3 but less dense than site G4.

Leaf Samples

Leaf samples consisted of 5 leaves from 20 vines for a total of 100 leaves per sample. Samples were collected between 1230 and 1320 and the average temperature was 24˚C in 2006; between 1135 and 1330 with an average temperature of 28.8˚C in 2007.

Site G6: Trestle Vineyard

35˚18’59”N, 120˚41’1”W; elevation: 117m

Figure 18. Site G6 with location of sampled vines circled and location of surrounding vegetation labeled.

Site G6 was located on the campus of Cal Poly State University near Hwy 1. The surrounding vegetation included natural vegetation and an avocado orchard. This orchard was maintained by University staff including a certified pest control advisor and a team of student workers. This vineyard was added to the survey in 2007. Applaud, Admire and Lorsban were applied for grape leafhopper and obscure mealybug in May and June (Table 4).

Leaf Samples

Leaf samples consisted of 5 leaves from 20 vines for a total of 100 leaves. Leaves were collected between 0820 and1020 and the average temperature was 16.6˚C.

Table 5. Insecticide applications for site G6-2007.

Location/ Date	Formulation	Chemical Name	Target Pest	Application Rate/Acre	Application Date
G6-2007	Applaud 70DF	Buprofezin	Grape leafhopper, Obscure mealybug	12 oz.	5/29
	Applaud 70DF	Buprofezin	Grape leafhopper, Obscure mealybug	12 oz.	5/30
	Admire 2 Flowable	Imidacloprid	Grape leafhopper, Obscure mealybug	30.76 oz.	6/1
	Applaud 70DF	Buprofezin	Grape leafhopper, Obscure mealybug	12.0 oz.	6/13
	Lorsban 4E	Chlorpyrifos	Obscure mealybug	30.76 oz.	6/18

Strawberry

A total of 9 strawberry fields were surveyed for phytoseiids (Table 1). Two fields in Santa Barbara County produced certified organic strawberries and the three fields in Ventura County were farmed conventionally. Four locations were surveyed one season only. Each strawberry field was maintained by one manager, a certified pest control advisor and a large work crew.

Leaf samples were collected between March and September for a total of 3-12 collection dates depending on the site. The range in collection dates was due to the early season mowing that occurred at some locations. Leaf samples from all locations consisted of 20 leaves from 5 rows for a total of 100 leaves and were gathered from the midlevel section of the strawberry plant. The lower leaves of the plant collected dust and sand and leaves near the crown of the plant received too much sunlight; both environments are less likely to maintain a population of phytoseiids (S. Finch, personal communication, March 6, 2006).

Insecticide application information for strawberries was not available. Each location conducted releases of *P. persimilis*; however, the dates of the releases were not available (Table 6).

Table 6. Phytoseiid releases in strawberry, 2006 and 2007.

Location	Species	Rate of Release/acre	Frequency
S1a	None	----	----
S1b	*P. persimilis*	10,000/acre	Not Available
S2	*P. persimilis*	10,000/acre	Not Available
S3	*P. persimilis*	10,000/acre	Not Available
*S4	*P. persimilis*	25,000/ac to interior of block	Over four week period
		35,000/ac to perimeter of block	Over four week period
S5	*P. persimilis*	10,000/acre	Not Available
*S6	*P. persimilis*	25,000/ac to interior of block	Over four week period
		35,000/ac to perimeter of block	Over four week period
S7	*P. persimilis*	10,000/acre	Not Available

*Persimilis release schedule for sites S4 and S6:

Week 1: 5,000 p/ac. to perimeter of block

Week 2: 10,000 p/ac. to perimeter of block; 5,000 to interior of block

Week 3: 10,000 p/ac. to perimeter of block; 5,000 to interior of block

Week 4: 10,000 p/ac. to perimeter of block; 5,000 to interior of block

Totals: 35,000 *P. persimilis*/ac released along the perimeters; 25,000 persimilis/ac released within the interior of the blocks.

Site S1: Betteravia Ranch

34˚56’6”N, 120˚21’32”W; elevation 92m

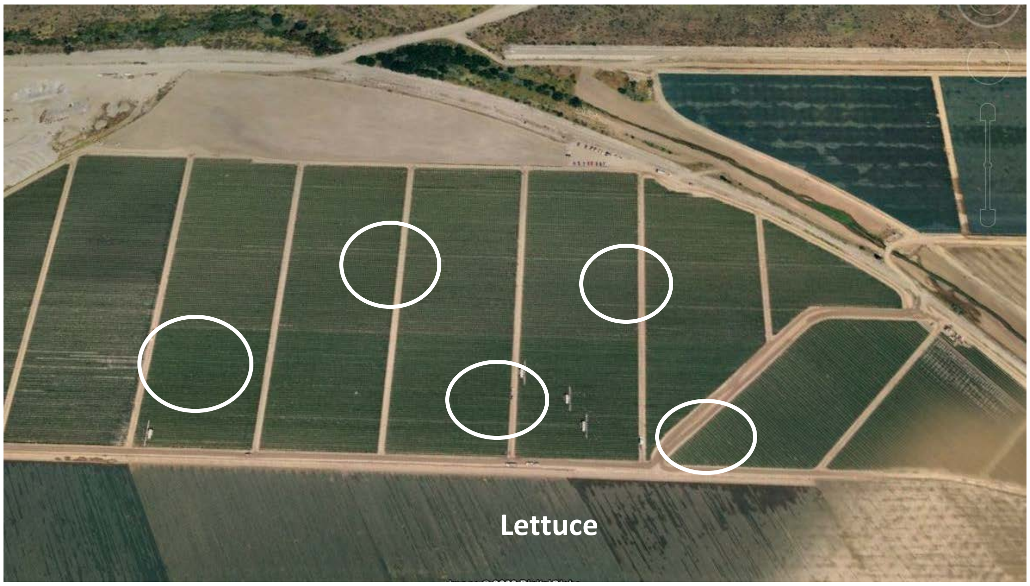

Figure 19. Site S1 with sampled areas circled and location of neighboring lettuce crop labeled.

Site S1 was planted adjacent to vegetable row crops (Fig. 19). *Phytoseiulus persimilis* were released at an approximate rate of 10,000/acre (Table 6).

Leaf Samples

Sampling occurred March through September for a total of 11 sample dates. Leaves were collected between 0930 and 1345 and the average temperature was 20˚C in 2006. This field provided the fewest phytoseiids and tetranychids in Santa Barbara County in 2006 and was not surveyed in 2007.

Site S2: Donavan Ranch

34˚58’53”N, 120˚27’15”W; elevation 58m

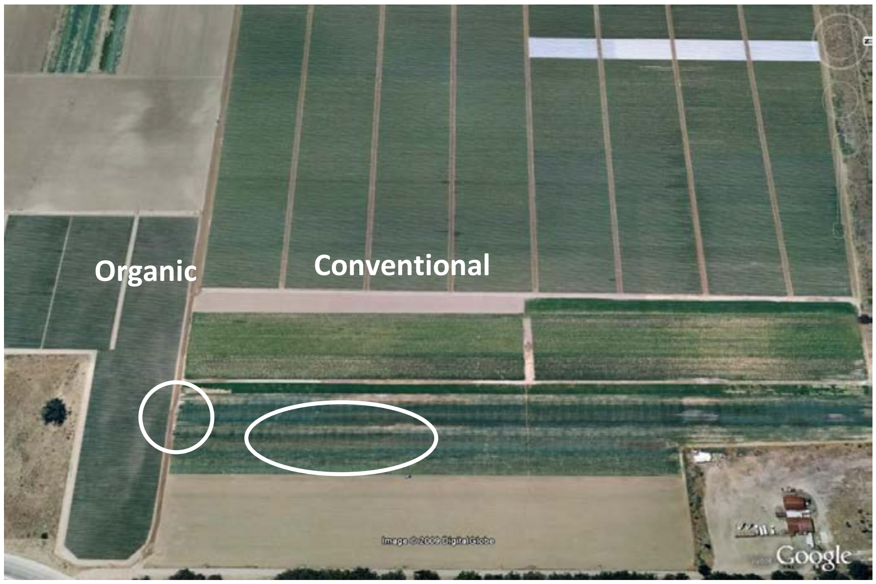

Figure 20. Site S2 with organic and conventional blocks labeled and sampled areas circled.

Site S2 produced conventional and organic strawberries. Both parcels were sampled and data for each were recorded separately in 2006. *Phytoseiulus persimilis* were released in the organic block at an approximate rate of 10,000/acre (Table 6).-The organic block was mowed and not available for sampling in 2007.

Leaf Samples

Sampling occurred March through September for a total of 12 sampling dates. Leaves were collected between 1015 and 1245 and the average temperature was 19˚C in 2006; between 0945 and 1220 with an average temperature of 18.8˚C in 2007.

Site S3: Sisquoc Field

34˚52’8”N, 120˚17’48”W; elevation: 129m

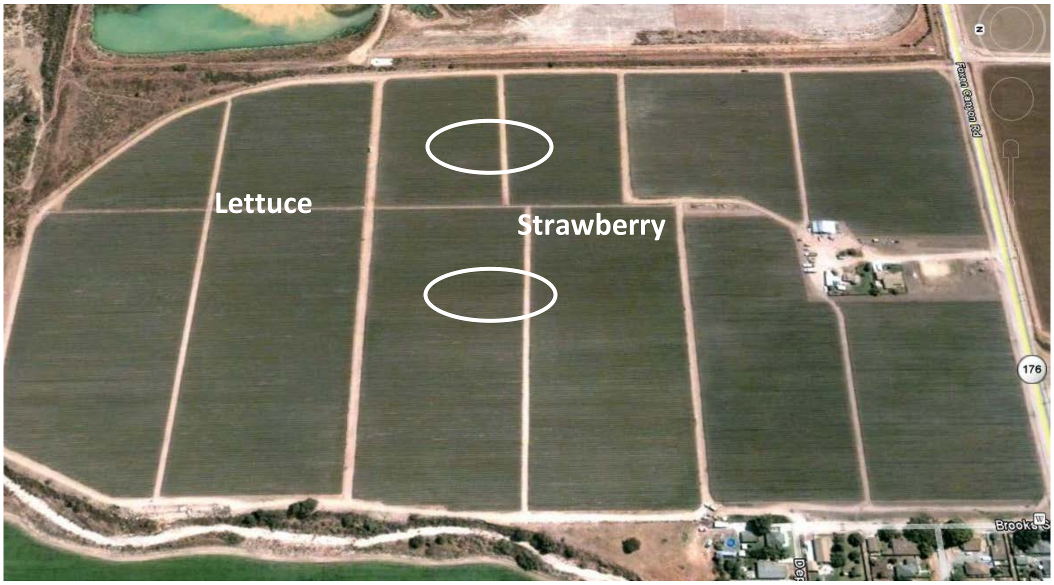

Figure 21. Site S3 with sampled areas circled and location of neighboring lettuce crop labeled.

Site S3 was planted alongside lettuce row crops (Fig. 21). The two strawberry blocks sampled were removed and not replanted after the 2006 season and was, therefore, not sampled in 2007. *Phytoseiulus persimilis* were released by the work crew at an approximate rate of 10,000/acre (Table 6).

Leaf Samples

Sampling occurred March through September for a total of 11 sampling dates. Leaves were collected between 0830 and 1450 and the average temperature was 22.5˚C.

Site S4: Donlon Ranch

34˚11’22”N, 119˚09’27”W; elevation: 16m

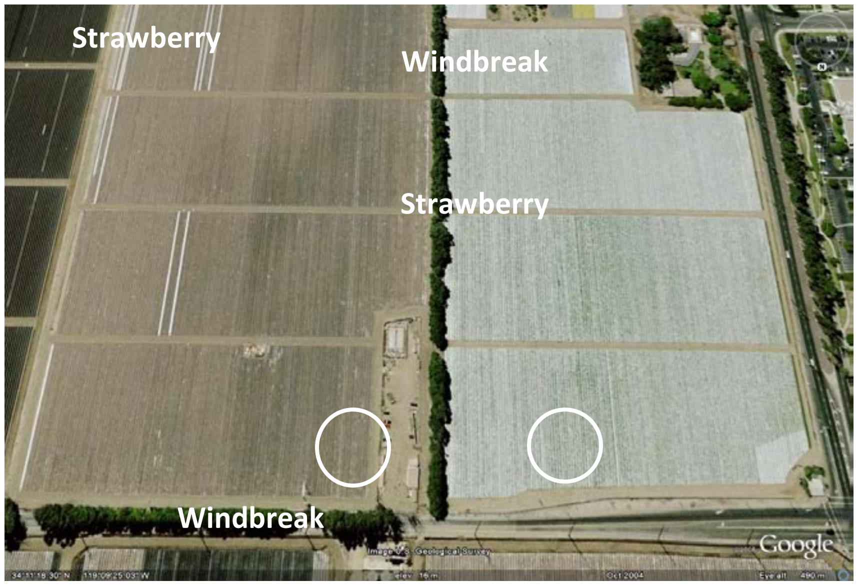

Figure 22. Site S4 with sampled areas circled and location of windbreaks labeled.

Site S4 was located between another strawberry operation and a residential area along E. Wooley Road in Oxnard (Fig. 22). *Phytoseiulus persimilis* were released by the work crew at an approximate rate of 10,000/acre (Table 6).

Leaf Samples

Sampling occurred April through June for a total of three sampling dates. The field was mowed in July both seasons. Leaves were collected between 1120 and 1400 and the average temperature was 18.0 ˚C in 2006; between 1020 and 1155 with an average temperature of 17.7˚C in 2007.

Site S5: Davis Ranch

34˚08’47”N, 119˚05’50”W; elevation 5m

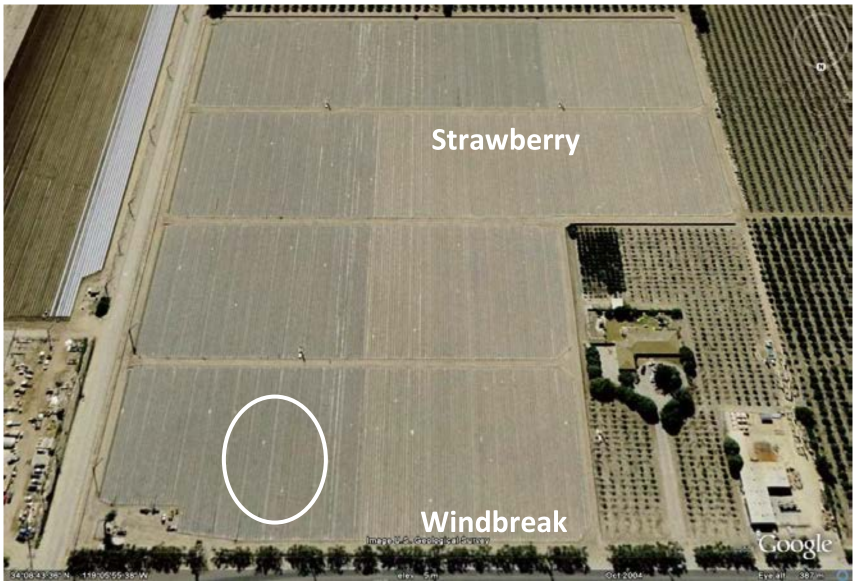

Figure 23. Site S5 with sampled area circled and location of windbreak labeled.

Site S5 was located at the intersection of Hueneme and Wood Road in Oxnard (Fig. 23). *Phytoseiulus persimilis* were released by the work crew at an approximate rate of 10,000/acre (Table 6).

Leaf Samples

Sampling occurred March and June for four sample dates in 2006. Leaves were collected between 1030 and 1445 and the average temperature was 18.0˚C. This field was mowed in July and provided the fewest number of phytoseiids in Ventura County. Sampling did not continue in 2007.

Site S6: Sammis Ranch

34˚52'07"N, 120˚17'23"W; elevation: 129 m.

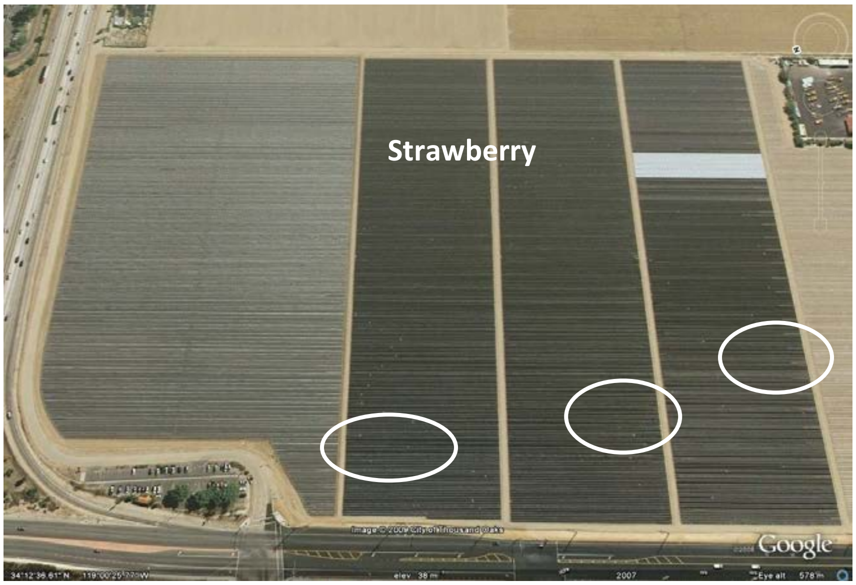

Figure 24. Site S6 with sampled areas circled.

Site S6 is located near the intersection of Pleasant Valley and Santa Rosa Road in Camarillo (Fig. 24). *Phytoseiulus persimilis* were released by the work crew at an approximate rate of 10,000/acre (Table 6).

Leaf Samples

Samples were collected between March and June for 5 sample dates in 2006 and 2007. The field was mowed by the July both seasons. Leaves were collected between 1045 and 1330 and the average temperature was 20.5˚C; between 1240 and 1350 with an average temperature of 19.0˚C in 2007.

Site S7: Eraud Farms

34˚52’23”N, 120˚28’17”W; elevation: 71m

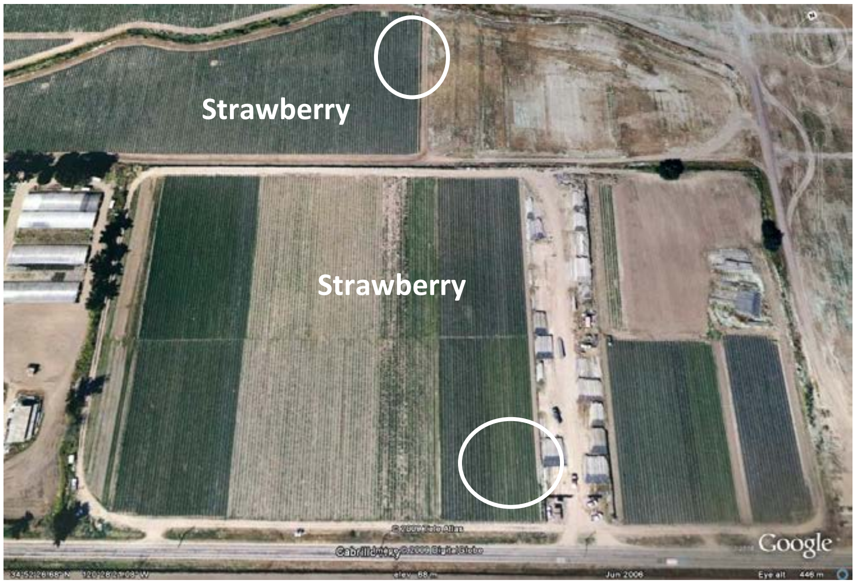

Figure 25. Site S7 with sampled rows circled.

Site S7 was located on the outskirts of Orcutt on Hwy 1 and produced only certified organic strawberries (Fig. 25). This field site was added to the survey in 2007. *Phytoseiulus persimilis* were released by the work crew at an approximate rate of 10,000/acre (Table 6). Lygus (*Lygus hesperus*) was the pest of greatest concern at this field. A portion of the plants were heavily damaged and removed.

Leaf Samples

Sampling occurred between July and September for a total of four dates in 2007. The sampled blocks were mowed by the end of September. Leaves were collected between 0930 and 1445 and the average temperature was 18.8˚C.

Distribution Patterns

Distribution is one element of species behavior, a fundamental life process that evolved for the purpose of survival in a selected environment (Taylor et al., 1978; Taylor, 1984). The degree of dispersal is relative to other individuals and is density-dependent (Taylor et al., 1978). Species distribution is described as aggregated, random or regular. Waters (1959) defined aggregation as a function of 5 different responses: response to the physical environment, the host plant, behaviors related to reproduction, attraction to other individuals of the same species, and interactions with other organisms. Reproductive related behaviors explained further includes more time spent in one place with sufficient prey available and the resulting increase in the predator's reproductive rate (Nachman, 1981). A regular or uniform distribution pattern suggests an organism's independence from other individuals (Taylor, 1984). The space between individuals is more equal than random and, therefore, the location of one is not influenced by the location of another. Uniform distribution suggests more equal spacing between organisms relative to a random distribution pattern.

Distribution patterns differ among species and the spatial level examined (Zhang & Sanderson, 1993). Zhang and Sanderson (1993) describe spatial levels as leaflets among a leaf, leaves on a branch or among a plant, or a plant across plants; the latter being the highest level on this spatial scale. Tetranychids have an aggregated distribution pattern (Zhang & Sanderson, 1993) while phytoseiids typically have a random distribution, with the exception of type I individuals. *Phytoseiulus persimilis* shows a random distributed among plantings while foraging, but then aggregates among leaves and tetranychid colonies (McMurtry & Croft, 1997; Zhang & Sanderson, 1993), thereby, aggregating in response to prey at lower spatial levels - prey per leaflet within a leaf (Zhang & Sanderson, 1993). Conversely, type III *Amblyseius andersoni* search randomly among leaflets and leaves within a branch or plant and have an aggregated distribution pattern at higher spatial levels, on leaves of a branches or a plant (Zhang & Sanderson, 1993). In this instance, more predators were found on branches with less prey. Type II *Galendromus occidentalis* showed an aggregated response to prey at higher spatial levels, per leaflet within a branch or plant, while the response to prey per leaflet within a leaf appeared random (Zhang & Sanderson, 1993).

The density dependent nature of distribution is supported by a study of the predator-prey interaction between *P. persimilis* and *T. urticae* (Nachman, 1981). Phytoseiid observations showed that predator distribution improves as the pest population increases, agreeing with Taylor’s power law. The population densities of both species varied according to the overall population. Random distribution was observed when densities were low and aggregation was more apparent when densities were high (Nachman, 1981). Individuals displaying random distribution do not defend territories and their location does not depend on the presence or absence of another (Taylor et al., 1978). Random distribution resulting from low population densities occurs when one organism cannot efficiently locate and interact with another individual (Taylor et al. 1978). An aggregated pattern implies interconnectedness among individuals where the position of one does impacts that of another.

Calculation of Distribution Patterns

Statgraphics Centurion XVI.I software was used to determine if mite distribution was random, aggregated or uniform among leaves. A frequency histogram first tabulated the number of phytoseiids and tetranychids counted in each data set. An intensity rating scale was developed to represent the number of phytoseiids and tetranychids counted per leaf from each sample collected. The rating scale runs from 0 to 5 representing the number of mites counted. The histogram plotted the frequency each rating was assigned to each leaf within a sample.

The next step determined which distribution pattern best fit the curve of the frequency histogram. A Poisson regression model describes a random distribution and negative binomial empirical models explain an aggregated distribution. The Poisson regression provided the P-value and the percentage of deviance for each data set.

The frequency histogram provided the standard deviation and mean of each data set which were used to perform an additional calculation to verify the spatial pattern. The Sharov method, named for Alexei Sharov, PhD., calculates the coefficient of dispersion (CD). The formula for calculating the CD is SD^2/M. A CD < 1 is a regular distribution; CD ~ 1 is a random distribution and a CD > 1 is an aggregated distribution.

Slide mounting and Identification

Temporary Slide Mounts

Anatomical characters necessary for species identification of female phytoseiid mites can only be viewed under a compound microscope; therefore, phytoseiid collected were slide mounted and prepared for identification. Glass slides, round cover slips and Hoyer's mounting medium were used to prepare the specimens.

Early slide mounting attempts caused some of the specimens to burst seconds after coming into contact with Hoyer's medium. The mites were initially preserved in 70% ethanol but had to be introduced gradually to greater concentrations of water to more closely match that of the Hoyer's medium. An immediate change in water concentrations overwhelmed the cell contents and caused the specimen to burst (Humason, 1979). The subsequent slides were prepared as follows: Three small glass dishes were used. One dish received the mites and 70% ethanol from the contents of one vial. The second dish received 60% ethanol, and the third dish received 50% ethanol. Just enough of the ethanol was put into each dish to submerge the mites. The mites were removed from the first dish with a 5/0 natural hair paint brush and transferred to the dish with 60% ethanol and left for 20-30 minutes. These mites were then removed from the 60% dish to the 50% ethanol and again left for 20-30 minutes.

The glass slides were prepared during the waiting period. One glass slide was marked with two intersecting lines drawn with a Sharpie Fine Point® from opposing corners to form an X. The point of intersection marked the center of slide and was used as a guide for consistent placement of the Hoyer's medium in the center of each slide. An eye dropper was used to apply a small amount of Hoyer's to the center of the slide at the point of intersection. Care was taken to ensure the appropriate amount of medium was applied to the slide. An insufficient amount of Hoyer's allowed trapped air pockets to remain underneath the cover slip and potentially cause the specimen to darken over time. Too much Hoyer's and the cover slip would not seal properly and the slide would not dry sufficiently. The barrel of the eyedropper was filled with medium, lifted from the bottle, and two drops were expelled back into the bottle without squeezing the eyedropper. The third drip of medium was held over the center of the slide and allowed to drop on to the center of the slide by way of gravity, not added pressure. The medium was not squeezed from the eyedropper for two reasons. Squeezing the medium from the eyedropper pushed air into the medium and resulted in unwanted air bubbles. The second reason was due to the difficulty in controlling the size of the drop applied to the slide when the eyedropper was squeezed (Y. Ouyang, personal communication, April, 2007).

Once the drop of Hoyer's was centered on the slide, any air bubbles in the medium were removed with the paint brush. One phytoseiid was lifted from the final solution of ethanol and set on a paper towel to allow the ethanol to evaporate. The specimen was then placed ventral side down in the center of the drop of Hoyer's and pushed down into the medium with the paint brush. A round glass cover slip was secured with forceps and slowly placed over the specimen. The cover slip was angled to touch the left edge to the slide first, then gradually laid across the Hoyer's in an effort to minimize the development of air bubbles. Gentle pressure was applied to the cover slip as the medium spread uniformly to the perimeter of the cover slip. An adhesive label was attached to the right side of the slide complete with the field site location and date of collection. The labeled slides were then set on a slide warmer to dry. The slide warmer was set to #6 on the temperature dial which equated to approximately 20° C. Each batch of completed slides were left to dry for a minimum of four days before the specimen could be identified.

Approximately 85% of phytoseiids collected were slide mounted as not all specimens were suitable for identification. As an example, immature and male individuals do not have the characters necessary to identify phytoseiid species. Additionally, gravid females were less desirable specimens because the egg can obscure these characters when viewed though a compound microscope.

Identification

Anatomical characters of adult females were examined to identify phytoseiids. Identification was accomplished with a dichotomous key being developed by Beth Grafton-Cardwell and Jim McMurtry. At the time of this writing, the key had not yet been published.

Three internal structures are specific to the phytoseiid family – the tritosternum, apotele claw, and the stigmata and peritreme (Figures 26, 27 & 28). The shape and size of the ventrianal shield indicates the sex of the phytoseiid. The ventrianal shield of a male is a large inverted triangle shape that extends the width of the abdomen (Fig. 31). The ventrianal shield of a female varies in shape depending on the species, but the size is notably smaller than the male and occupies only a small portion of the lower abdomen. The three structures associated with the ventral shield help determine the maturity of the phytoseiid. An immature specimen will have underdeveloped sternal, genital and ventrianal shields that are difficult to decipher (Fig. 32).

The dorsal and ventral setal patterns of the female phytoseiid were examined with the dichotomous key to determine the genus and species. A final identification label was adhered to the left side of the glass slide. An identification sheet was also filled out for each slide that included the collections site and identification of each.

The number of anterolateral setae was first examined to determine the subfamily of the specimen. The presence of five or 6 pairs of anterolateral setae (j3, z2, z4, s4, z3 and/or s6) placed specimens in the Phytoseiinae or Typhlodrominae subfamilies (Fig. 29). Four pairs of anterolateral setae (j3, z2, z4, and s4) placed specimens in the subfamily Amblyseiinae (Fig. 30). Once this distinction was made, the length and location of other setae were examined to determine the genus. The shape of structures associated with the dorsal and ventral shield determined the species. See Appendix for identification details on each genus and species identified.

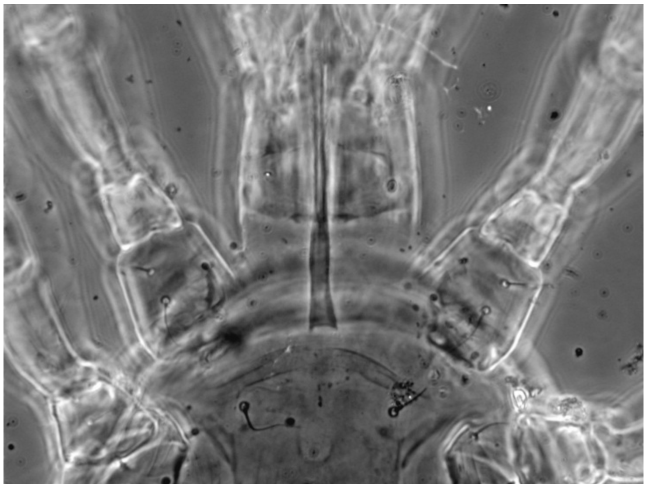

Figure 26. Tritosternum of an adult female phytoseiid.

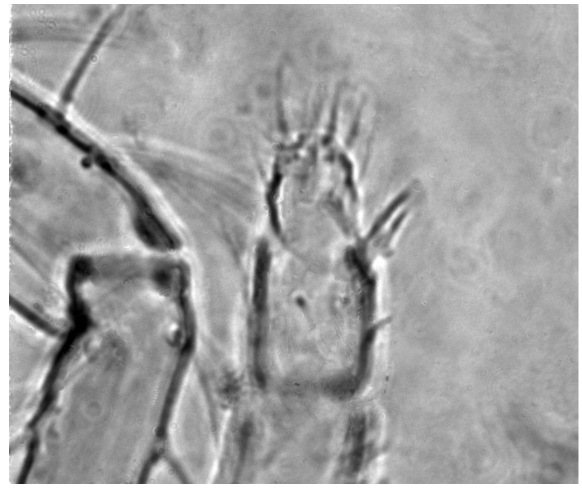

Figure 27. Apotele claw of an adult female phytoseiid.

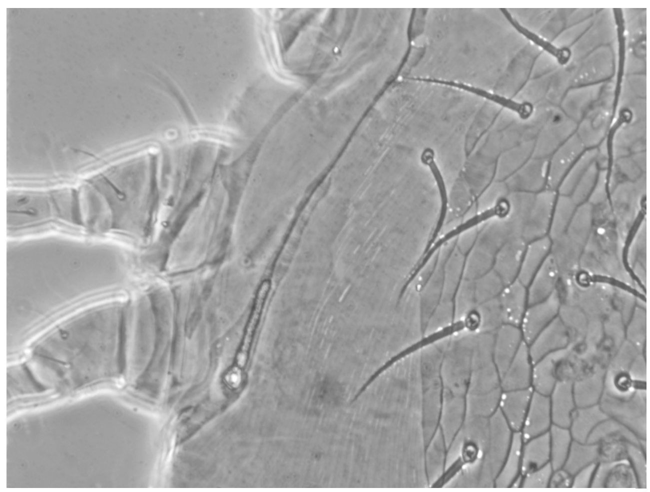

Figure 28. Stigmata and peritreme of an adult female phytoseiid.

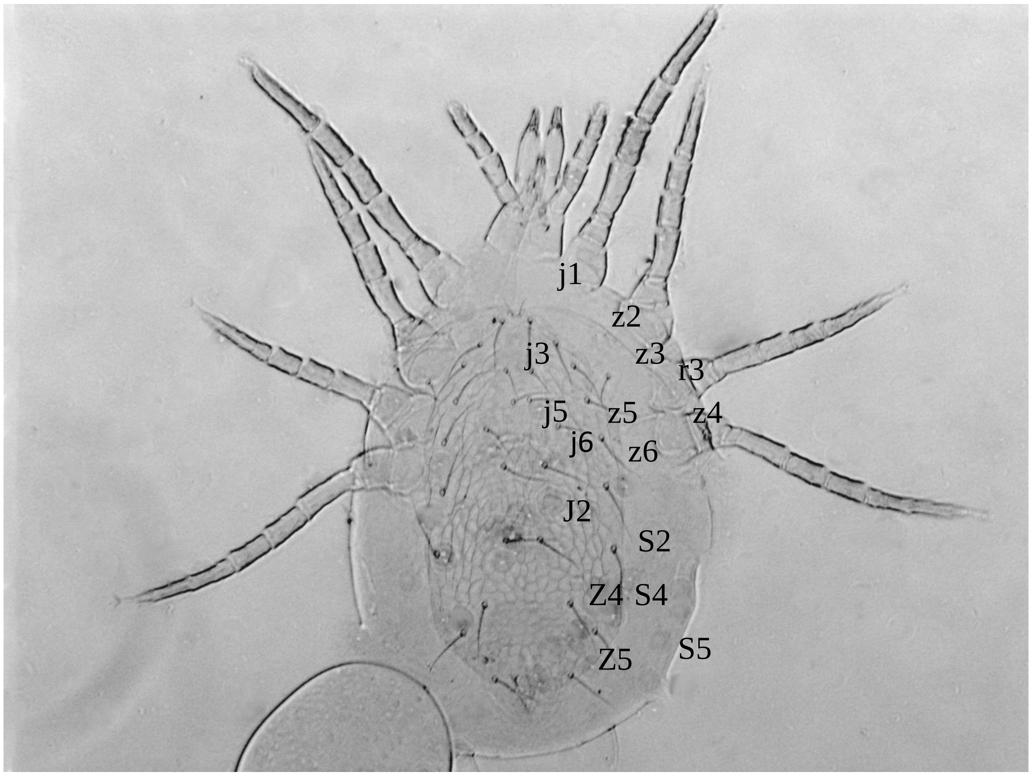

Figure 29. Setal pattern of Typhlodrominae family.

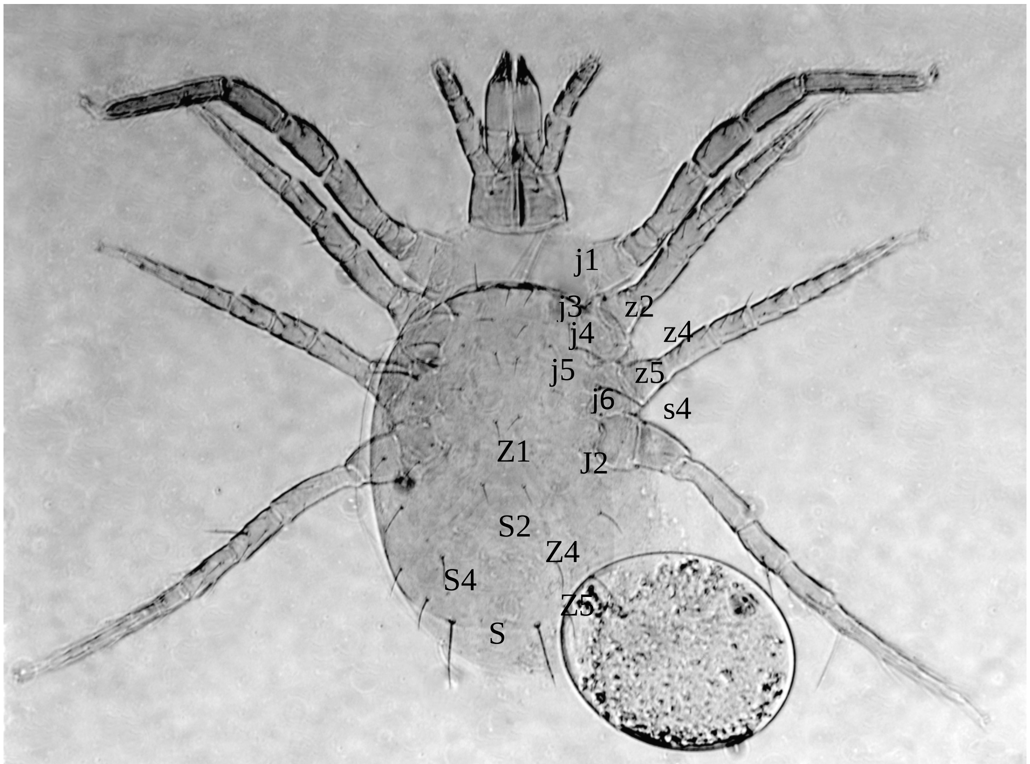

Figure 30. Setal pattern of Amblyseiinae family.

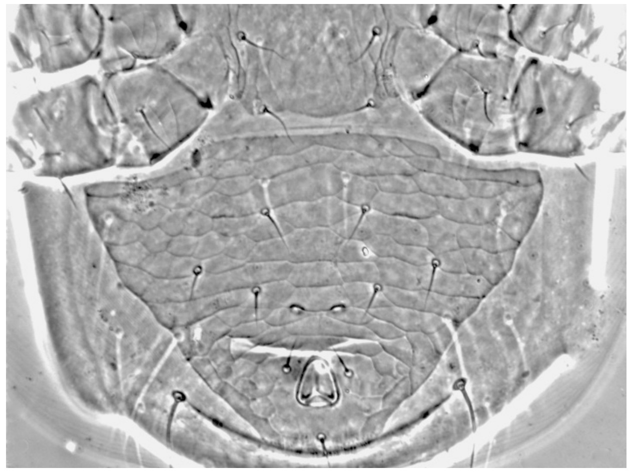

Figure 31. Large ventrianal shield of a male phytoseiid.

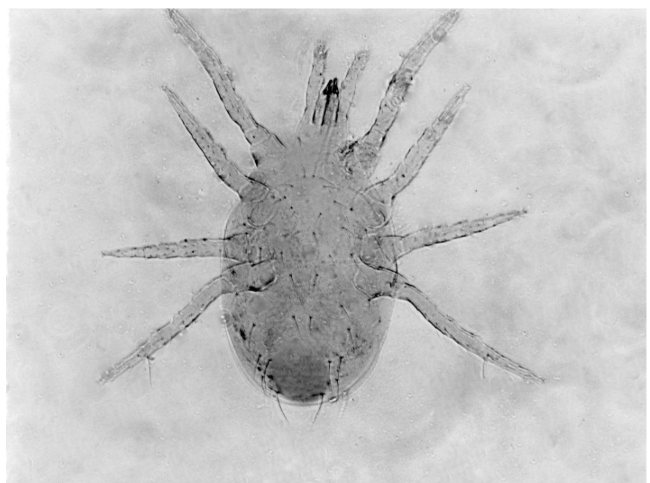

Figure 32. Slide mounted immature phytoseiid.

CHAPTER IV

RESULTS

Avocado

There were 16 collection dates in 2006 and 7 dates in 2007 for avocado. The average number of phytoseiids per leaf was 1.85 times greater in 2006 than in 2007 (Table 7) and the average number of *O. perseae* per leaf was 50 times greater in 2006 than 2007.

Table 7. Average number of phytoseiids and tetranychids counted on avocado, 2006 and 2007.

		Average Phytoseiid and Tetranychid Mites Counted per Leaf	
Year	Field Site	*Phytoseiidae*	*Oligonychus perseae*
2006	A1	0.09	1.90
	A2	0.09	1.90
	A3	0.05	8.2
Season Avg.		0.07	4.0
2007	A1	0.05	0.01
	A2	0.35	0.0
	A3	0.003	0.23
Season Avg.		0.13	0.08

Euseius stipulatus made up 93.7% and 100% of the total phytoseiid species identified on avocado in 2006 and 2007, respectively (Table 8). In 2006, *E. quetzali* McMurtry made up 3.8% and *A. similoides* and *T. eharai* made up 1.3% of the season total of 79 phytoseiids. *Oligonychus perseae* was site identified in the field and was the only tetranychid species present in the three orchards.

Table 8. Phytoseiids identified on avocado, 2006 and 2007.

		Phytoseiid Species			
Year	Field Site	*Euseius stipulatus*	*Euseius quetzali*	*Amblyseius similoides*	*Typhlodromina eharai*
Type		Type IV	Type IV	Type III	Type III
2006	A1	6	0	1	1
	A2	28	3	0	0
	A3	40	0	0	0
Total		74 (93.7%)	3 (3.8%)	1 (1.3%)	1(1.3%)
2007	A1	18	0	0	0
	A2	23	0	0	0
	A3	2	0	0	0
Total		43 (100%)	0	0	0

Oligonychus perseae activity began in June at A1-2006 and the population peaked in October with an average of 5.8 mites per leaf (Fig. 33). Phytoseiid *T. eharai* was present in July and *E. stipulatus* and *A. similoides* were identified in September and October (Fig. 34). The phytoseiid population peaked with an averaged 0.14 per leaf on the last collection date in late October (Fig. 33). In 2007, *O. perseae* was located in August only with an averaged 0.04 mites per leaf (Fig. 35). *Euseius stipulatus* activity began in April with the season high of 0.28 mites per leaf (Fig. 36). Fungal feeding tydeiid mites (genus unknown) were observed on 45% of the leaves sampled in April and may have served as an additional food source for the *Euseius* species and *T. ehari*. Applications of Agri-Mek and Omni Oil in June appeared likely suppressed *O. perseae*, predatory mites, and tydeiids both seasons (Figs. 33 and 35).

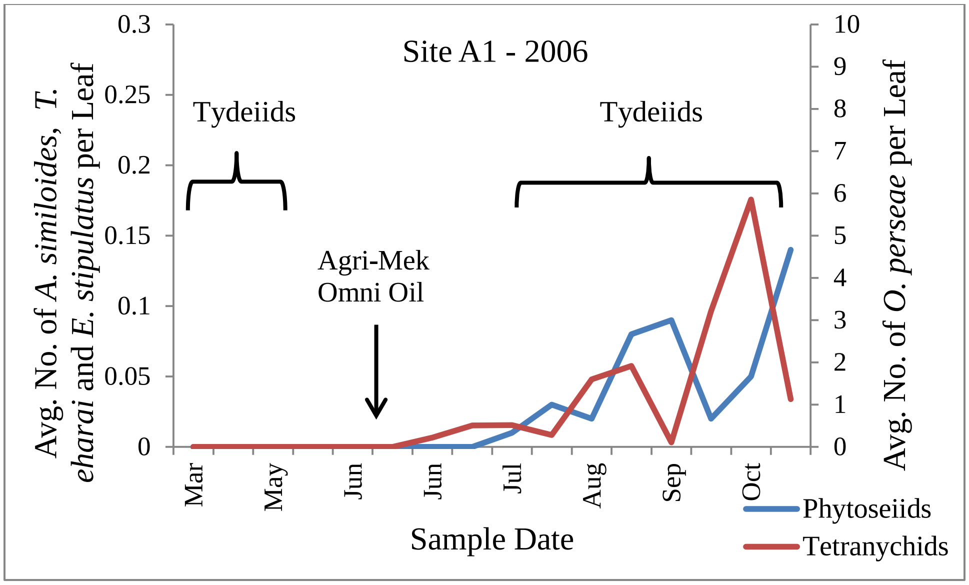

Figure 33. Average number of phytoseiids (*Amblyseius similoides, Typhlodromina eharai*, *Euseius stipulatus*) and tetranychids *(Oligonychus perseae)* per leaf at A1, 2006. Agri-Mek and Omni Oil were applied on June 14.Tydeiids were present March through May and July through October.

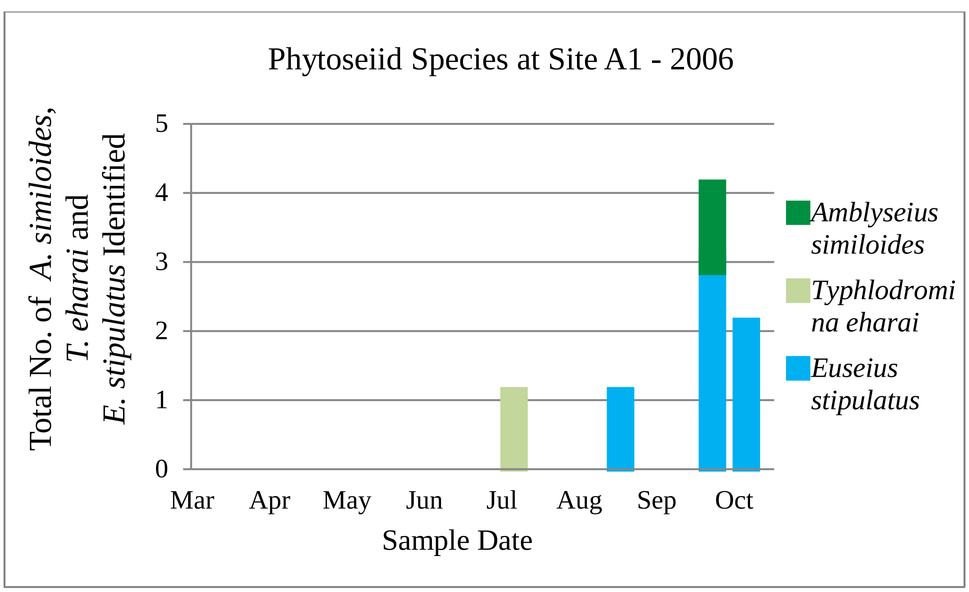

Figure 34. Total number of phytoseiids (*Amblyseius similoides*, *Typhlodromina eharai*, *Euseius stipulatus*) slide mounted and identified at A1, 2006.

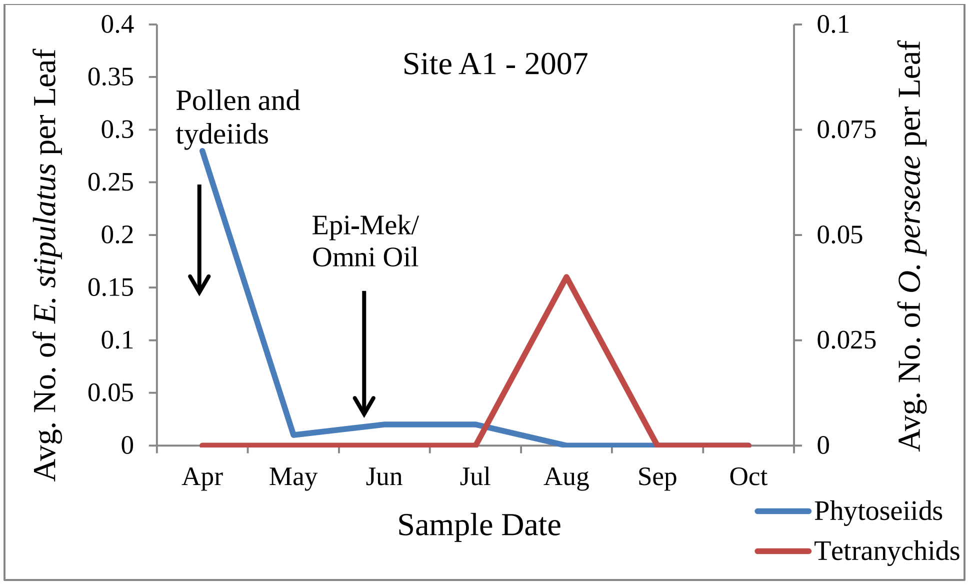

Figure 35. Average number of phytoseiids (*Euseius stipulatus*) and tetranychids (*Oligonychus perseae)* per leaf at A1, 2007. Epi-Mek and Omni Oil were applied on June 11.Pollen and tydeiids were present in April.

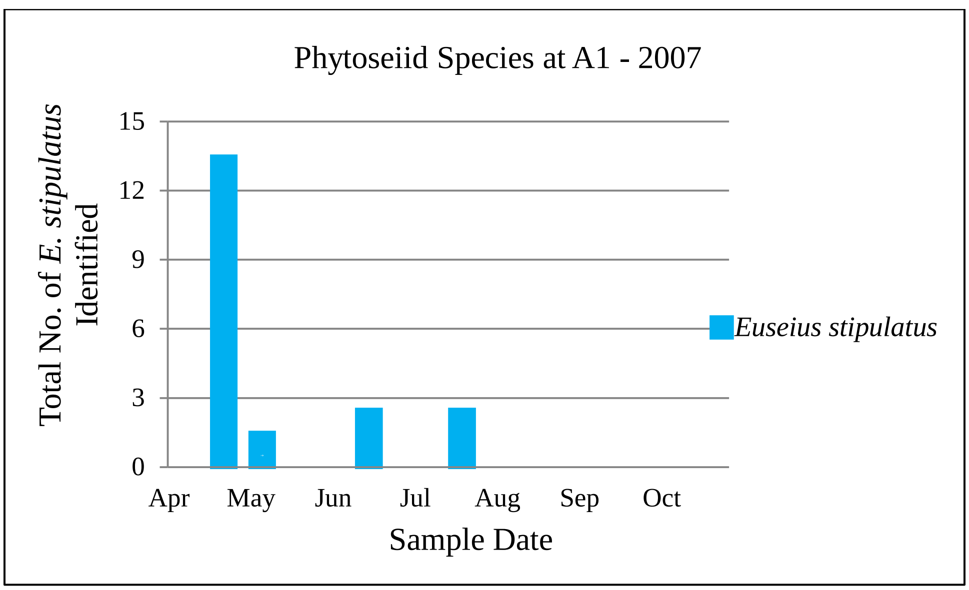

Figure 36. Total number of phytoseiid species (*Euseius stipulatus*) slide mounted and identified at A1, 2007.

Oligonychus perseae was located in June at site A2-2006 and peaked with an average of 5.7 mites per leaf (Fig. 37). *Euseius* spp. appeared in June (Fig. 38) and peaked with an average of 0.47 mites per leaf (Fig. 37). *Oligonychus persea* was not found at A2-2007, but *E. stipulatus* was present (Fig. 39). Phytoseiid activity began in April and peaked in August with an average of 1.3 mites per leaf (Fig. 40).

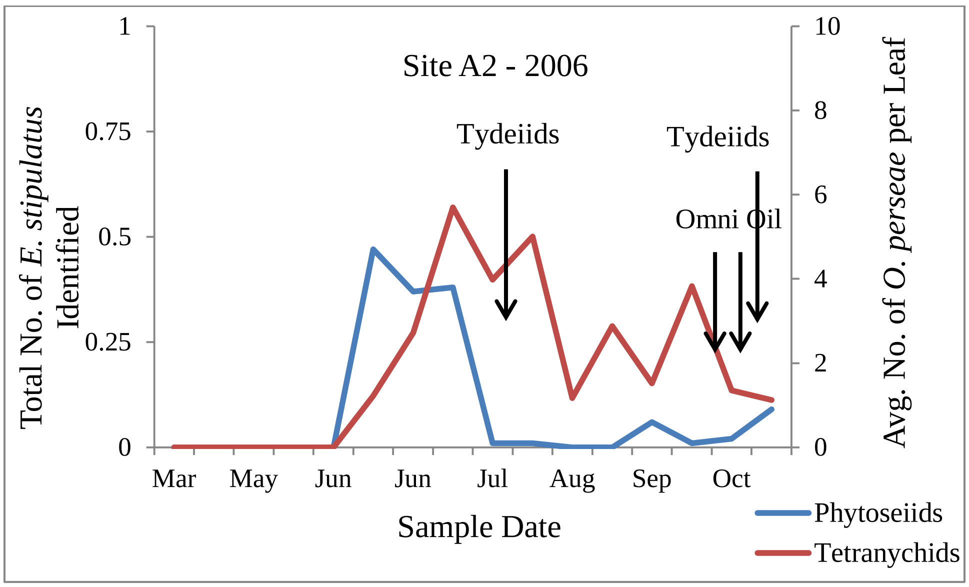

Figure 37. Average number of phytoseiids (*Euseius stipulatus*) and tetranychids (*Oligonychus perseae)* per leaf at A2, 2006. Omni oil was applied on September 19 and 26.Tydeiids were present in July and October.

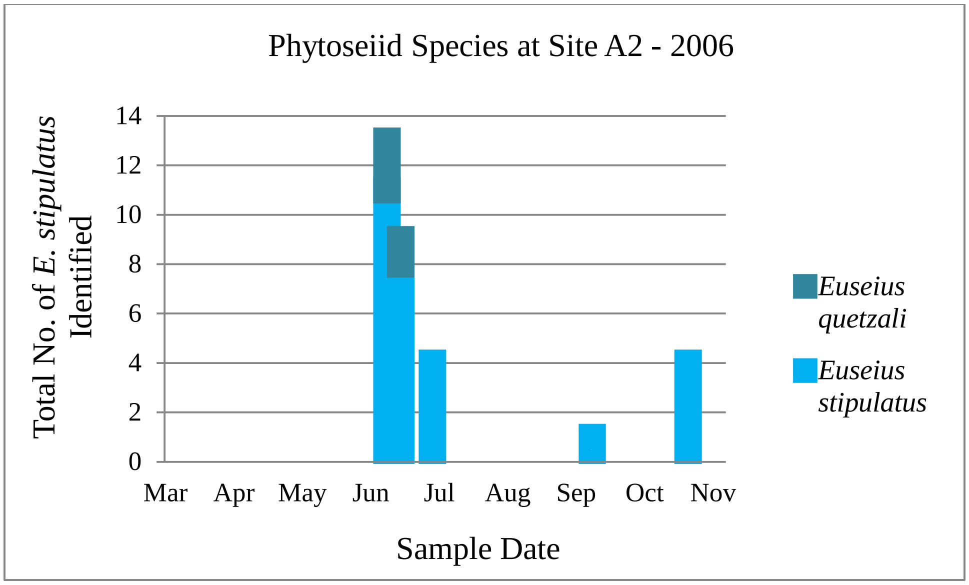

Figure 38. Total number of phytoseiid species (*Euseius stipulatus*) slide mounted and identified at A2, 2006.

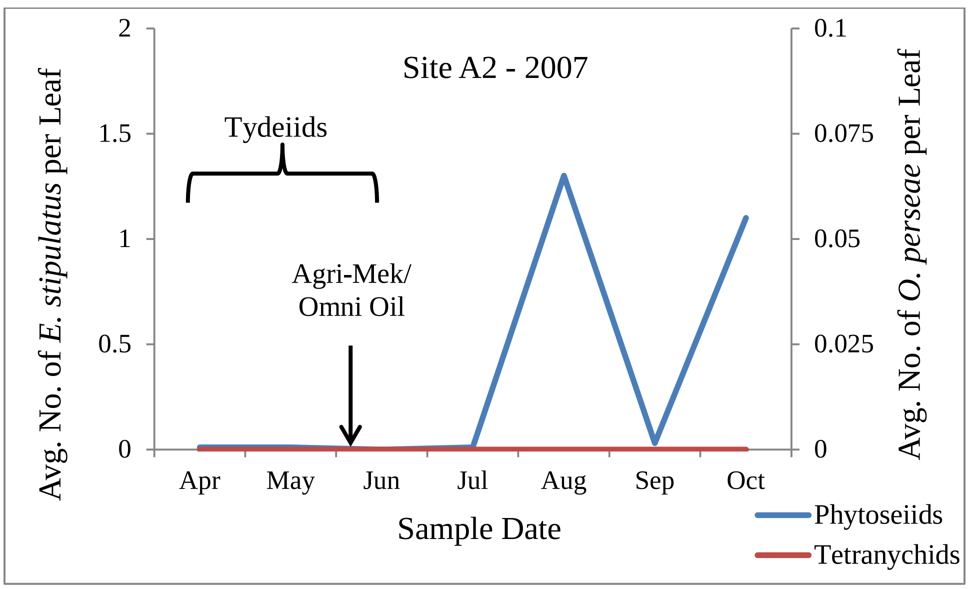

Figure 39. Average number of phytoseiids (*Euseius stipulatus*) and tetranychids (*Oligonychus perseae)* per leaf at A2, 2007. Agri-Mek and Omni Oil were applied on June 19.Tydeiids were present in April, May, and June.

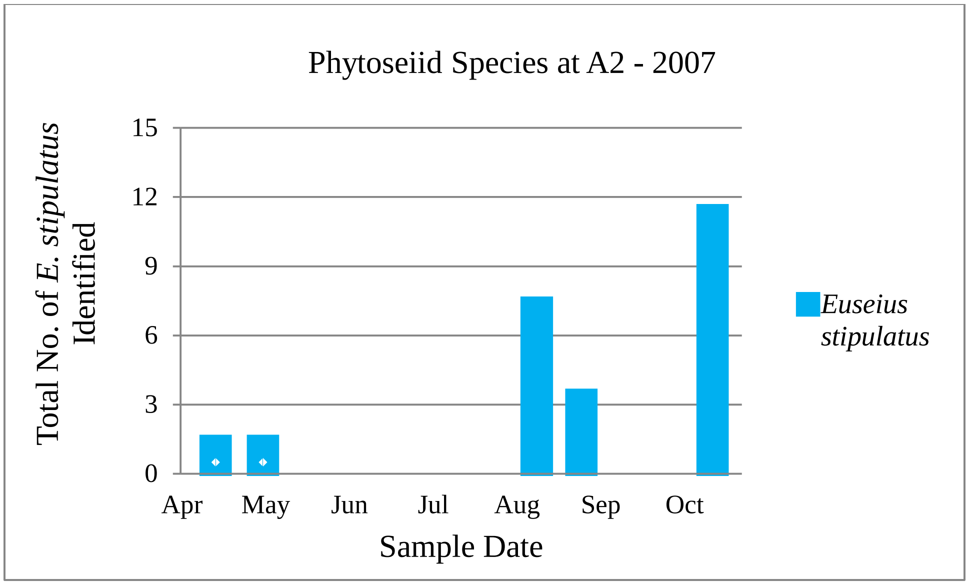

Figure 40. Total number of phytoseiid species (*Euseius stipulatus*) slide mounted and identified at A2, 2007.

Oligonychus persea were active from March through October at A3-2006 and peaked in July with an average of 41.2 mites per leaf (Fig. 41). *Euseius stipulatus* and *E. quetzali* were active from June through October (Fig. 42) and peaked on the last sample date with an average of 0.26 per leaf (Fig. 41). An application of Agri-Mek and Omni Oil on July 17 appeared to suppress both pest and predatory mites (Fig. 41). *Euseius stipulatus* were located in September only in 2007 (Fig. 44) with an average of 0.02 per leaf (Fig. 43). *Oligonychus persea* were most active in April, June and September with an average of 0.19, 0.81 and 0.31 mites per leaf, respectively, per leaf (Fig 43).

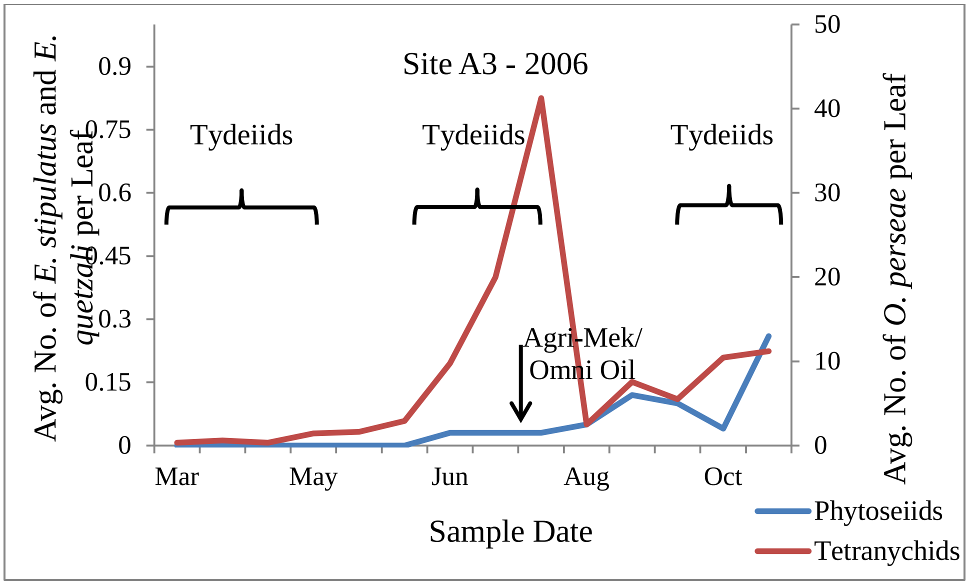

Figure 41. Average number of phytoseiids (*Euseius stipulatus* and *Euseius quetzali*) and tetranychids (*Oligonychus perseae)* per leaf at A3, 2006. Agri-Mek and Omni Oil were applied on July 17. Tydeiids were present in March through April, June and July, and September and October.

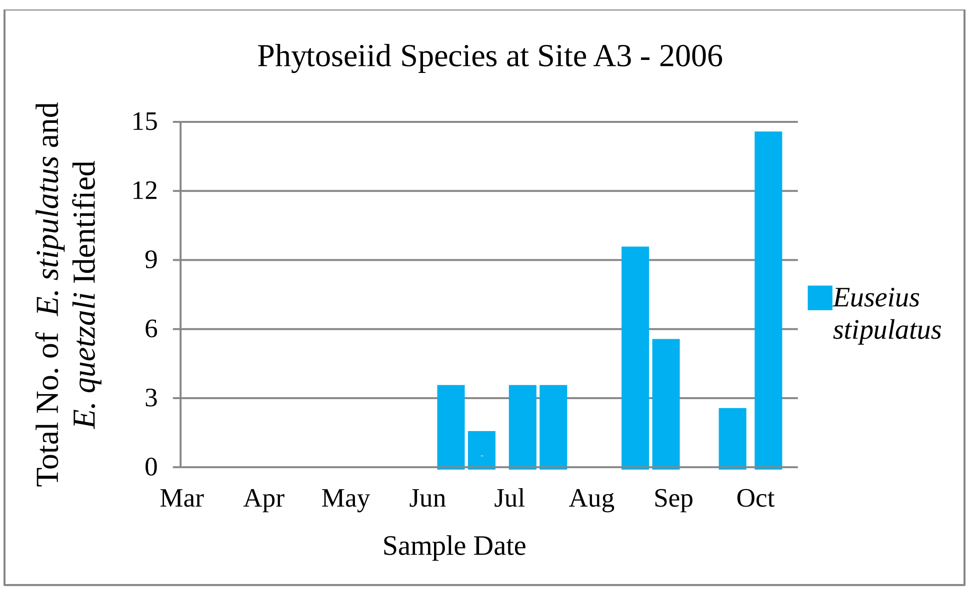

Figure 42. Total number of phytoseiids (*Euseius stipulatus* and *Euseius quetzali*) slide mounted and identified at A3-2006.

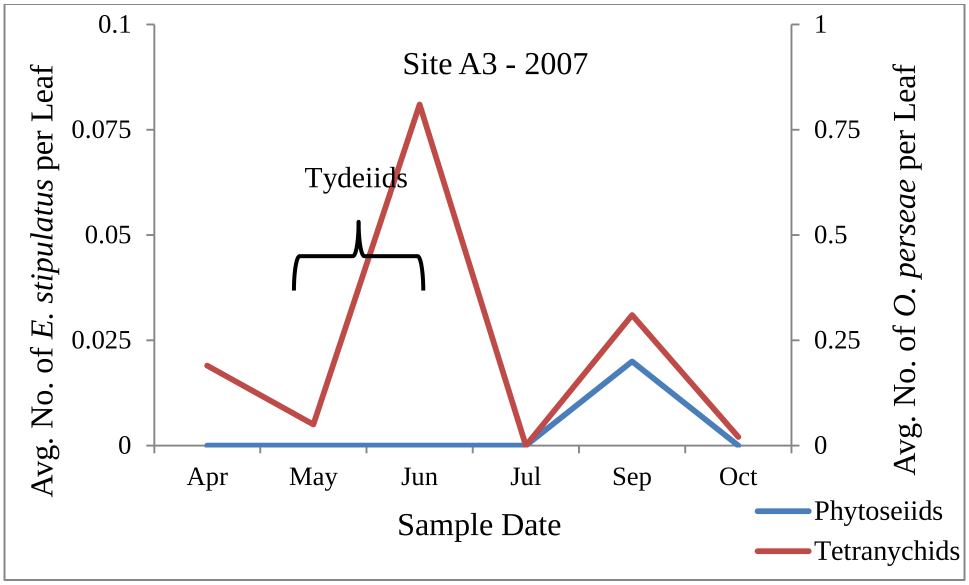

Figure 43. Average number of phytoseiids (*Euseius stipulatus*) and tetranychids (*Oligonychus perseae)* per leaf at A3, 2007. Tydeiids present in May and June.

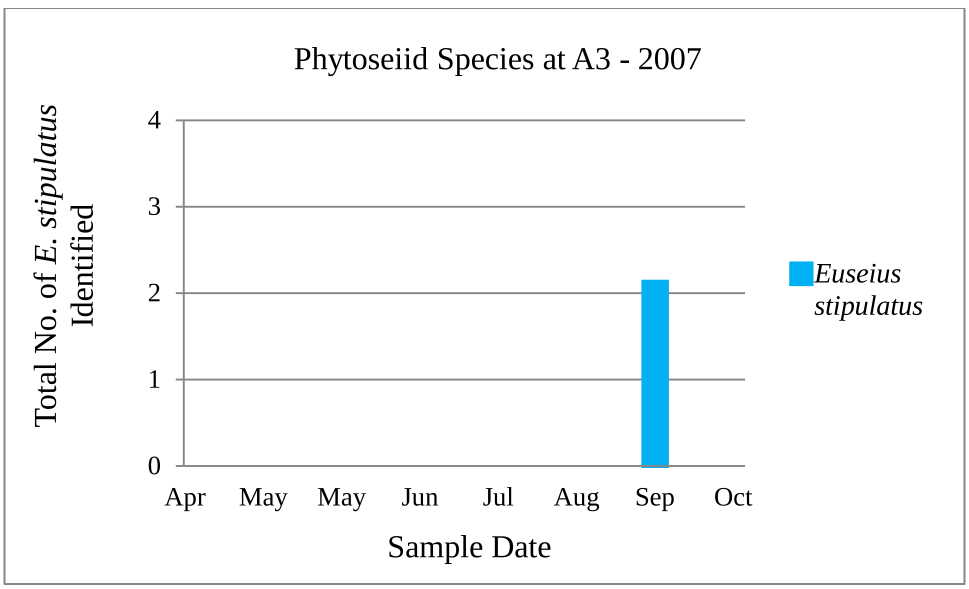

Figure 44. Total number of phytoseiids (*Euseius stipulatus*) slide mounted and identified at A3-2007.

Distribution Pattern

The CD for phytoseiids on avocados in 2006 and 2007 ranged from 0.95 and 1.12 and all but one population showed a random distribution (Table 9). The dominant phytoseiids were type IV *Euseius* species (Table 8). *Oligonychus perseae* consistently showed an aggregated distribution.

Table 9. Statistical findings for avocado, 2006 and 2007. The scale used to determine the CD: < 0.90 = regular; 0.90-1.10 = random; > 1.10 = aggregated.

				Poisson Regression			
Crop/Site	Year	Phytoseiids	Tetranychids	P-value		% of Deviance	
Avocado	2006			P	T	P	T
A1		0.96 Random	3.31 Aggregated	0.0000	0.0000	99.95%	89.38%
A2		0.97 Random	2.33 Aggregated	0.0000	0.0000	99.91%	93.29%
A3		0.95 Random	2.20 Aggregated	0.0000	0.0000	99.88%	68.91%
A1	2007	1.12 Aggregated	1.44 Aggregated	0.0000	0.0000	99.96%	99.99%
A2		0.96 Random	N/A	0.0000	0.0000	99.90%	100%
A3		1.0 Random	1.88 Aggregated	0.0000	0.0000	99.99%	99.25%

The pest and predator population patterns observed in avocado does not suggest that *E. stipulatus* regulated *O. perseae* because the population was capable of increasing in the presence of *E. stipulatus* at A2 and A3, 2006(Figs. 37 and 41) and *E. stipulatus* was present when *O. perseae* was absent (Figs. 35 and 39). The significant presence of *Euseius* species in April at A1-2007 (Fig. 35) was likely correlated to the heavy bloom period and an abundance of pollen grains that had fallen onto the leaves.

Cherimoya

There were 12 sample dates for cherimoya in 2006 and 7 in 2007. The average number of phytoseiids counted per leaf was 2.9 times greater in 2006 than in 2007, while the average number of *Eotetranychus* spp. were 1.7times greater in 2007 than in 2006 (Table 10).

Table 10. Average number of phytoseiids and tetranychids counted on cherimoya, 2006 and 2007.

		Average Phytoseiid and Tetranychid Mites Counted per Leaf	
Year	Field Site	*Phytoseiidae*	*Eotetranychus* spp.
2006	CH1	0.27	0.73
	CH2	0.10	0.51
	CH3	0.23	0.49
Season Avg.		0.2	0.58
2007	CH1	0.08	1.70
	CH2	0.04	1.0
	CH3	0.10	0.30
Season Avg.		0.07	1.0

Euseius stipulatus made up 86.0% and 90.7% of all phytoseiids identified on cherimoya in 2006 and 2007, respectively (Table 11). In 2006, *E. quetzali* made up 8.0% and *A. similoides* 6.0% of phytoseiids identified. In 2007, *G. occidentalis* made up 3.7%

and *E. quetzali*, *A. limonicus*, and *A. similoides* made up of 1.9% each of the identified phytoseiids. *Eotetranychus* spp. were the only tetranychid located on cherimoya.

Table 11. Phytoseiids identified on cherimoya, 2006 and 2007.

		Phytoseiid Species				
Year	Field Site	*Euseius stipulatus*	*Euseius quetzali*	*Amblydromalus limonicus*	*Amblyseius similoides*	*Galendromus occidentalis*
Type		Type IV	Type IV	Type III	Type III	Type II
2006	CH1	16	0	0	1	0
	CH2	4	0	0	0	0
	CH3	23	4	0	1	0
Total		43 (87%)	4 (8.0%)	0	2 (4.0%)	0
2007	CH1	8	0	1	1	1
	CH2	10	0	0	0	0
	CH3	31	1	0	0	1
Total		49 (90.7%)	1 (1.9%)	1 (1.9%)	1 (1.9%)	2 (3.7%)

Eotetranychus spp. appeared in March at CH1-2006 and peaked in May with an average of 3.32 mites per leaf (Fig. 45). *Euseius stipulatus* were active during May to November and *A. similoides* was located in July only (Fig. 46). In 2007, *Eotetranychus* spp. peaked in May with an average of 4.24 per leaf (Fig. 47). The population then decreased to an average of 0.08 per leaf on the last collection date in October (Fig. 47). *Euseius stipulatus* first appeared in April and was active through July when *G. occidentalis* appeared (Fig. 48). Phytoseiid activity peaked in July and September with an average of 0.12 mites per leaf, then decreased through October (Fig. 47).

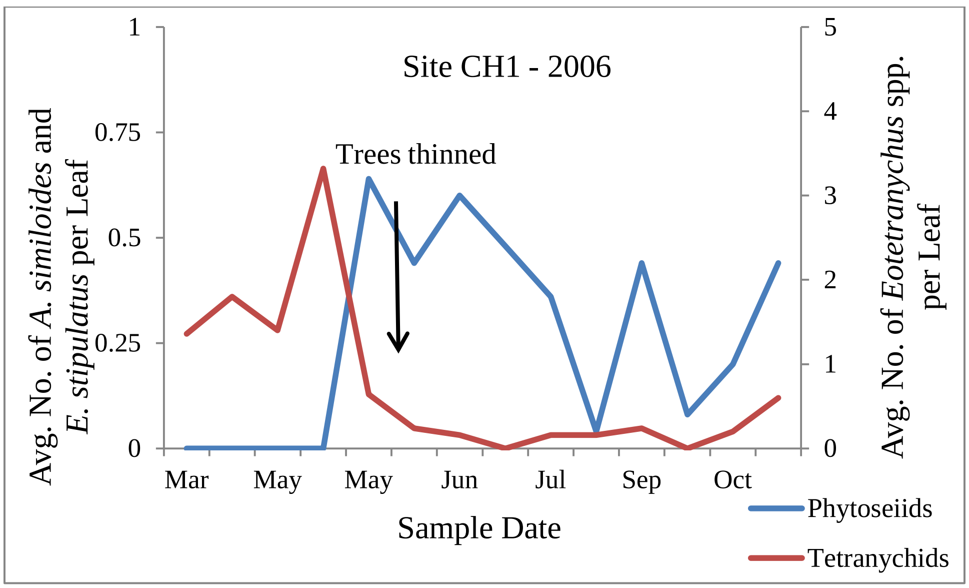

Figure 45. Average number of phytoseiids (*Amblyseius similoides* and *Euseius stipulatus*) and tetranychids (*Eotetranychus* spp.) per leaf at CH1, 2006. Trees were thinned on May 29.

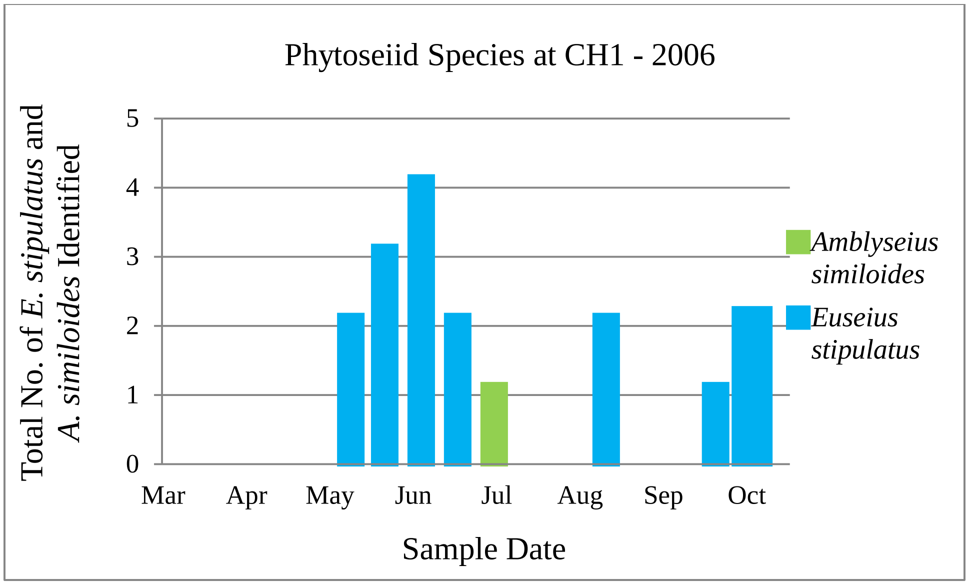

Figure 46. Total number of phytoseiids (*Euseius stipulatus* and *Amblyseius similoides*) slide mounted and identified at CH1, 2006.

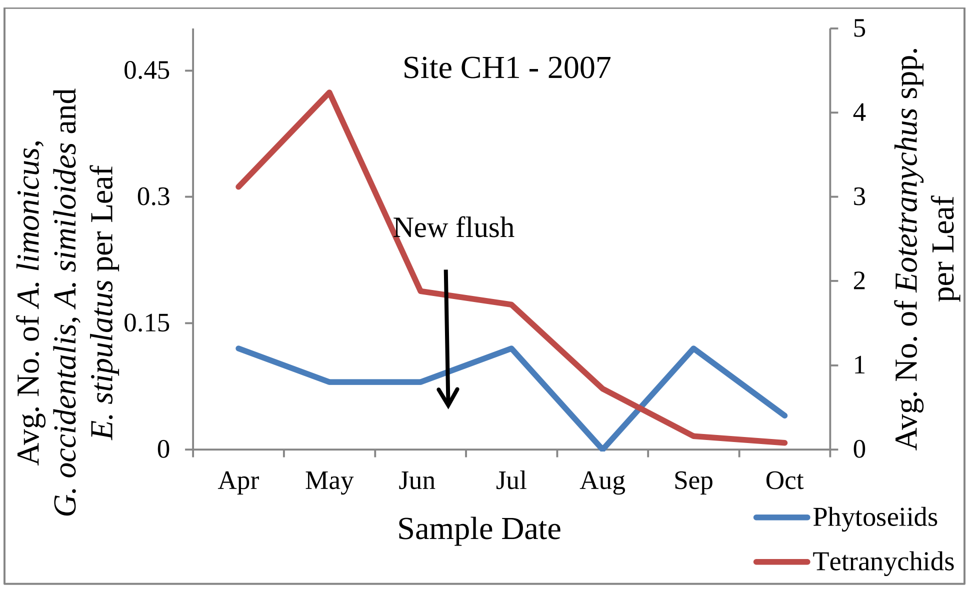

Figure 47. Average number of phytoseiids (*Amblydromalus limonicus*, *Galendromus occidentalis*, *Amblyseius similoides*, *Euseius stipulatus)* and tetranychids (*Eotetranychus* spp.) per leaf at CH1 in 2007. New flush was recorded on June 21.

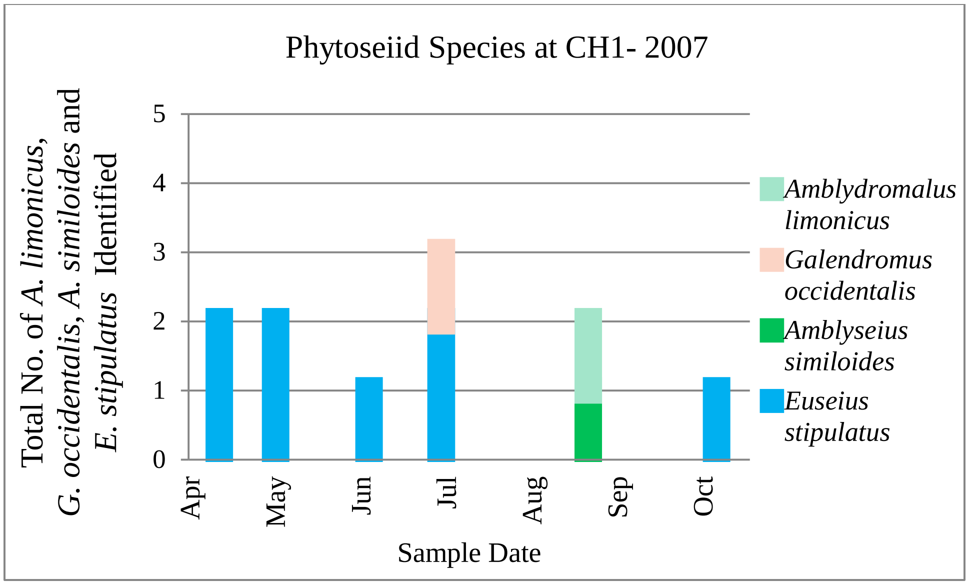

Figure 48. Total number of phytoseiids (*Amblydromalus limonicus*, *Galendromus occidentalis*, *Amblyseius similoides*, *and Euseius stipulatus*) slide mounted and identified at CH1, 2007.

Eotetranychus spp. at site CH2-2006 peaked in May with an average of 1.66 mites per leaf (Fig. 49). The population decreased to 0 in July, but rebounded by late July and was active through the beginning of November on the last sample date. *Euseius stipulatus* appeared in May (Fig. 50) and peaked with an average of 0.58 mites per leaf (Fig. 49). The population then decreased to zero in July, but rebounded and remained active through the last sample date in November. In 2007, *Eotetranychus* spp. activity began in April with the season's high population with an average of 2.8 mites per leaf (Fig. 51). The population ranged from an average of 0.12 to 1.18mites per leaf for the remainder of the season. *Euseius stipulatus* appeared in April (Fig. 52) and peaked in July with an average of 0.08 per leaf (Fig. 51). The population decreased to zero by September.

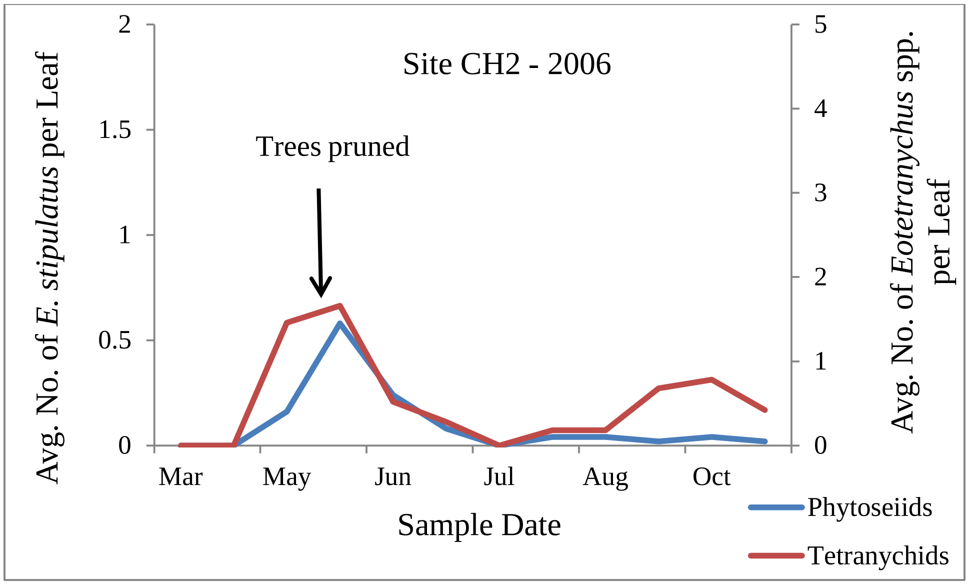

Figure 49. Average number of phytoseiids (*Euseius stipulatus*) and tetranychids (*Eotetranychus* spp.) per leaf at CH2, 2006. Trees were pruned on May 13.

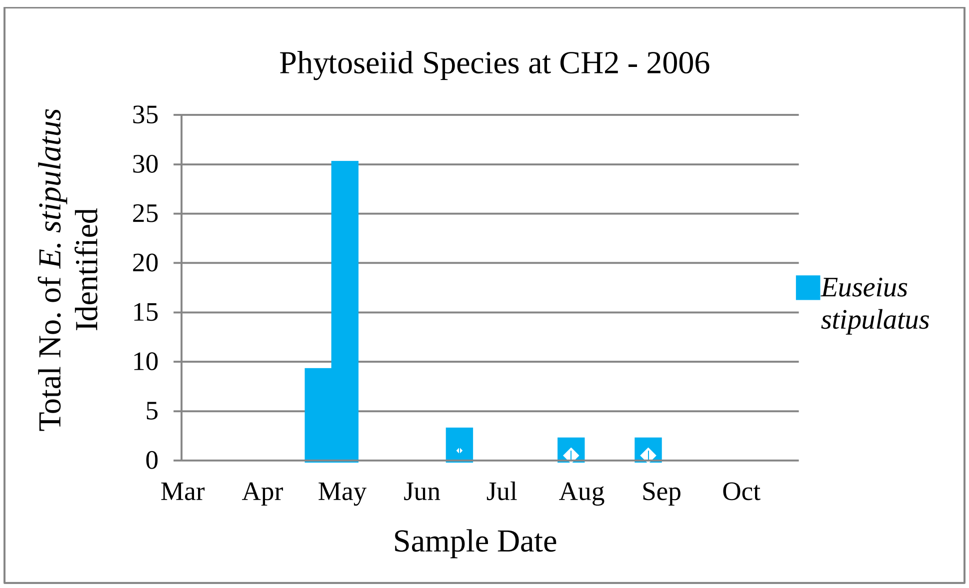

Figure 50. Total number of phytoseiids (*Euseius stipulatus*) slide mounted and identified at CH2, 2006.

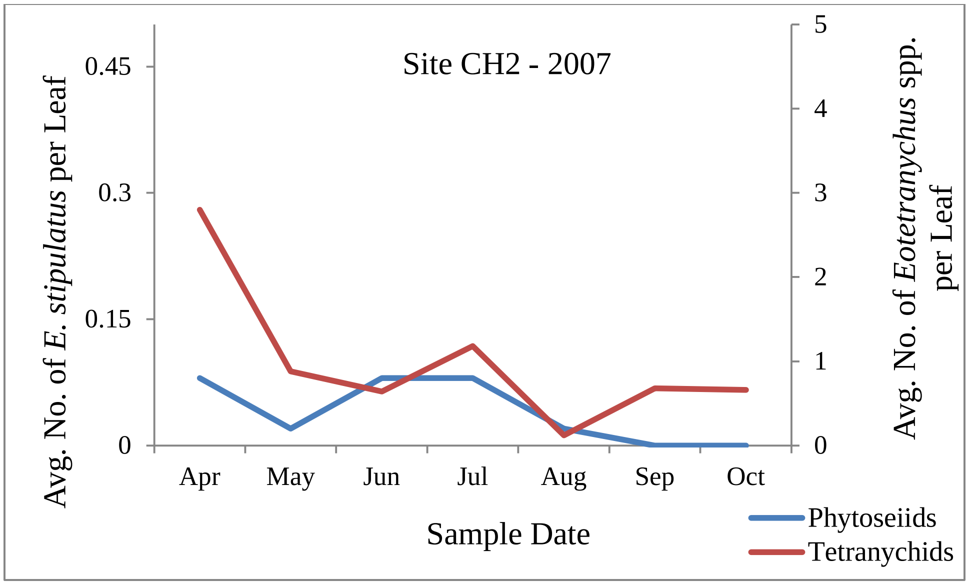

Figure 51. Average number of phytoseiids (*Euseius stipulatus*) and tetranychids (*Eotetranychus* spp.) per leaf at CH2 in 2007.

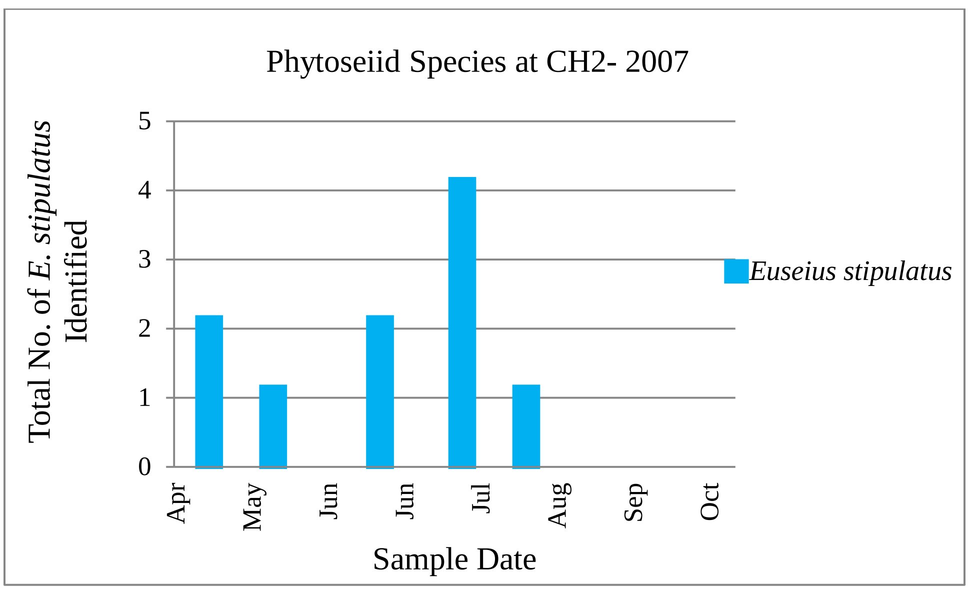

Figure 52. Total number of phytoseiids (*Euseius stipulatus*) slide mounted and identified at CH2, 2007.

Eotetranychus spp. appeared in May at CH3-2006, peaked with an average of 2.04 mites per leaf then decreased to 0.12 in October (Fig. 53). Phytoseiids *A. similoides*, *E. quetzali*, and *E. stipulatus* were active from May through October (Fig. 54), and peaked in June with an average of 0.4 mites per leaf (Fig. 53). In 2007, *Eotetranychus* spp. appeared and peaked in April on the first collection date with an average of 0.92 mites per leaf (Fig. 55). *Euseius stipulatus* appeared and peaked in April (Fig. 56) with an average of 0.28 mites per leaf and were active through August (Fig. 55). *Euseius quetzali* and *G. occidentalis* appeared in September and October (Fig. 56) with an average of 0.02 mites per leaf (Fig. 55).

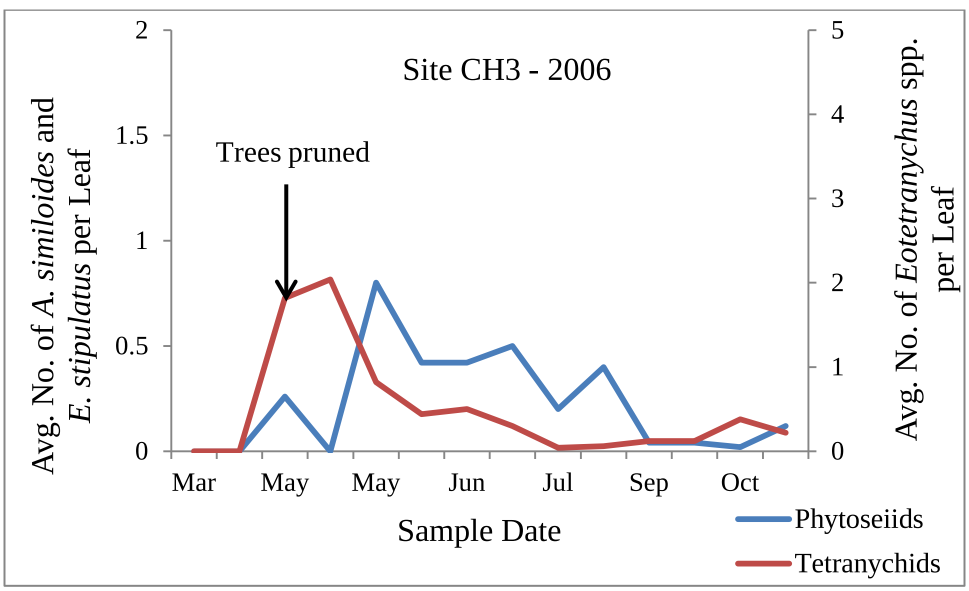

Figure 53. Average number of phytoseiids (*Amblyseius similoides* and *Euseius stipulatus)* and tetranychids (*Eotetranychus* spp.) per leaf at CH3, 2006. Trees were pruned on May 3.

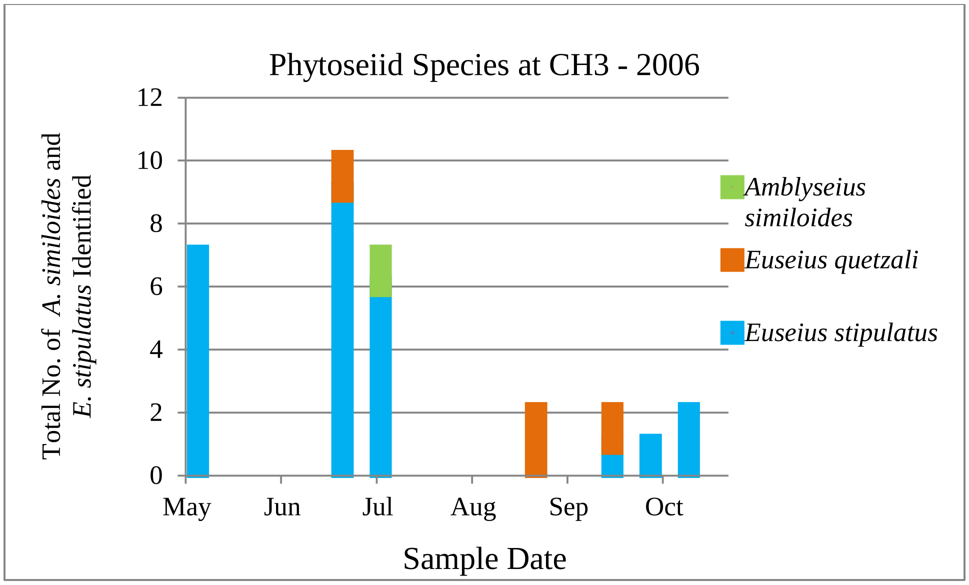

Figure 54. Total number of phytoseiids (*Amblyseius similoides, Euseius quetzali*, and *Euseius stipulatus*) slide mounted and identified at CH3, 2006.

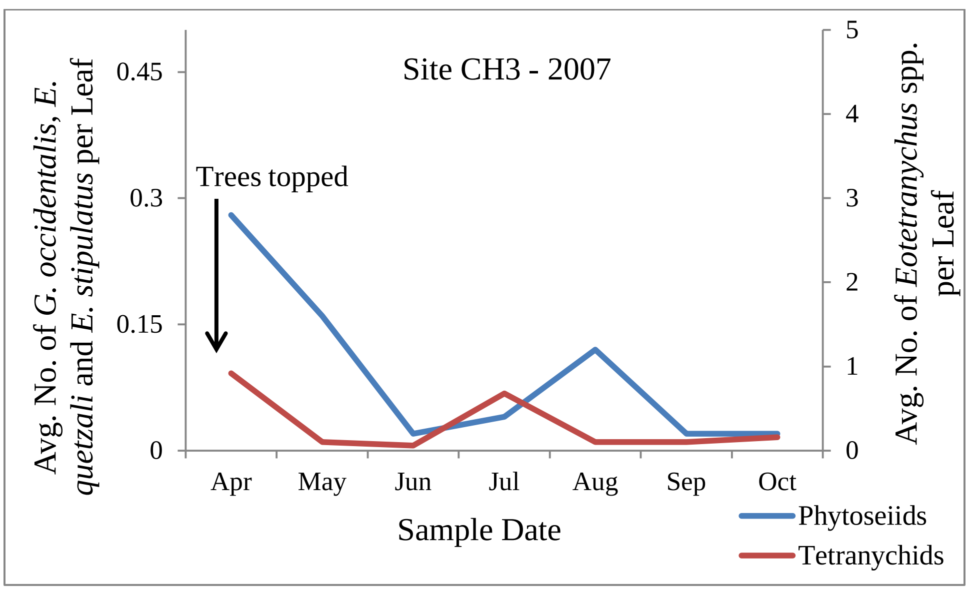

Figure 55. Average number of phytoseiids (*Galendromus occidentalis*, *Euseius quetzali*, and *Euseius stipulatus*) and tetranychids (*Eotetranychus* spp.) per leaf at CH3, 2007. Trees were topped on April 24.

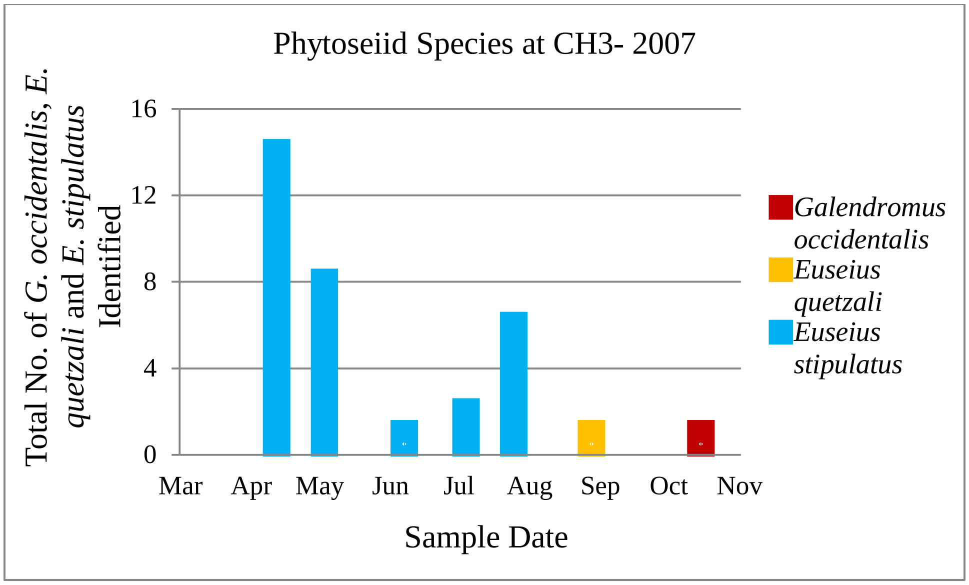

Figure 56. Total number of phytoseiids (*Galendromus occidentalis*, *Euseius quetzali*, and *Euseius stipulatus*) slide mounted and identified at CH3, 2007.

Euseius stipulatus at CH2-2006 appeared to respond to the pest population between April and July (Fig. 49), demonstrating a typical pest-predator relationship. However, the population trends in 2007 do not indicate these phytoseiids species regulated *Eotetranychus* spp. The minor presence of mealybugs, thrips, aphids and tydeiids during both seasons which may have served as additional food sources for phytoseiids. Other *Euseius* species are known to prey on *Eotetranychus* spp. (UC ANR publication 3436), but it has not been experimentally demonstrated that *E. stipulatus* does as well.

Distribution Pattern

The CD for phytoseiids on cherimoya in 2006 and 2007 ranged from 0.82 to 0.95 with the majority of the populations showing a random distribution pattern and *Eotetranychus* spp. were aggregated (Table 12). Therefore, effective regulation of *Eotetranychus* spp. by phytoseiids on cherimoya was not observed.

Table 12. Statistical findings for chereimoya, 2006 and 2007. The scale used to determine the CD: < 0.90 = regular; 0.90-1.10 = random; > 1.10 = aggregated.

				Poisson Regression			
Crop/site	Year	Phytoseiids	Tetranychids	P-value		% of deviance	
Cherimoya	2006			P	T	P	T
CH1		0.82 Regular	0.75 Regular	0.0000	0.0000	97.53%	93.13%
CH2		0.93 Random	0.88 Regular	0.0000	0.0000	99.96%	97.51%
CH3		0.84 Regular	1.16 Aggregated	0.0000	0.0000	98.13%	99.87%
CH1	2007	0.92 Random	1.25 Aggregated	0.0000	0.0000	99.69%	97.43%
CH2		0.95 Random	1.19 Aggregated	0.0000	0.0000	99.88%	96.37%
CH3		0.95 Random	1.19 Aggregated	0.0000	0.0000	99.47%	99.47%

<u>Caneberry</u>

Raspberry

The average number of phytoseiids counted per leaf on raspberries was 2 times greater in 2006 than in 2007(Table 13). The average number of tetranychids counted per leaf was nearly 4.2 times greater in 2007 than in 2006.

Table 13. Average number of phytoseiids and tetranychids counted on raspberry, 2006 and 2007.

		Average Phytoseiid and Tetranychid Mites Counted per Leaf	
Year	Field Site	*Phytoseiidae*	*Tetranychidae*
2006	C1a	0.08	0.20
	C2	0.04	0.07
	C3	0.15	0.57
	C4	0.07	0.46
	C5	0.14	0.20
Total		0.10	0.30
2007	C1a	0.10	2.75
	C3	0.05	1.10
	C4	0.02	0.57
	C5	0.04	0.57
Total		0.05	1.25

Amblydromalus limonicus and *E. stipulatus* accounted for 45.7% and 34%, respectively, of the phytoseiids identified on raspberry in 2006; *N. californicus* and *P. persimilis* followed with 8.7% and 7.2% of the total, respectively (Table 14). *Phytoseiulus persimilis* accounted for 40% of the phytoseiids identified in 2007, followed by *A. limonicus*, *E. stipulatus*, and *N. californicus* with 21%, 18% and 14%, respectively. *Tetranychus urticae* and *Eotetranychus* spp. were site identified in the field and were present at each caneberry location and approximately 12 times more *T. urticae* were found than *Eotetranychus* spp.

Table 14. Phytoseiid species identified on raspberry, 2006 and 2007.

Year	Field Site	Phytoseiidae Species						
		Euseius stipulatus	*Amblydromalus limonicus*	*Typhlodromina eharai*	*Typhlodromus rhenanoides*	*Metaseiulus johnsoni*	*Neoseiulus californicus*	*Phytoseiulus persimilis*
Type		Type IV	Type III	Type III	Type III	Type III	Type II	Type I
2006	C1a	1	19	1	0	0	10	1
	C2	3	3	0	0	0	0	1
	C3	0	41	0	0	0	0	2
	C4	11	0	0	0	0	1	6
	C5	32	0	0	0	5	1	0
Totals		47 (34.0%)	63 (45.7%)	1 (0.7%)	0	5 (3.6%)	12 (8.7%)	10 (7.2%)
2007	C1a	1	19	1	1	0	8	11
	C3	8	2	0	0	0	6	15
	C4	3	0	0	0	5	0	4
	C5	6	0	0	0	0	0	10
Totals		18 (18.0%)	21 (21.0%)	1 (1.0%)	1 (1.0%)	5 (5.0%)	14 (14.0%)	40 (40.0%)

The population of *T. urticae* and *Eotetranychus* spp. peaked at C1a-2006 in August with an average of 0.6 mites per leaf (Fig. 57). Phytoseiids also peaked in August with an average of 0.1 and 0.2 mites per leaf and *P. persimilis* in were released on June 23 and Aug 8 (Fig. 57). Phytoseiid species collected and identified in August include *A. limonicus*, *N. californicus*, and *P. persimilis* (Fig. 58). Tetranychids peaked in 2007 with an average of 10.6 and 12.1 mites per leaf in July and August, respectively (Fig. 59). Phytoseiids also peaked in July and August with an average of 0.2 and 0.3 mites per leaf, respectively (Fig. 59). Phytoseiids collected and identified during the population peak included *T. eharai*, *T. rhenanoides*, *A. limonicus*, *E. stipulatus*, *N. californicus*, and *P. persimilis* (Fig. 60).

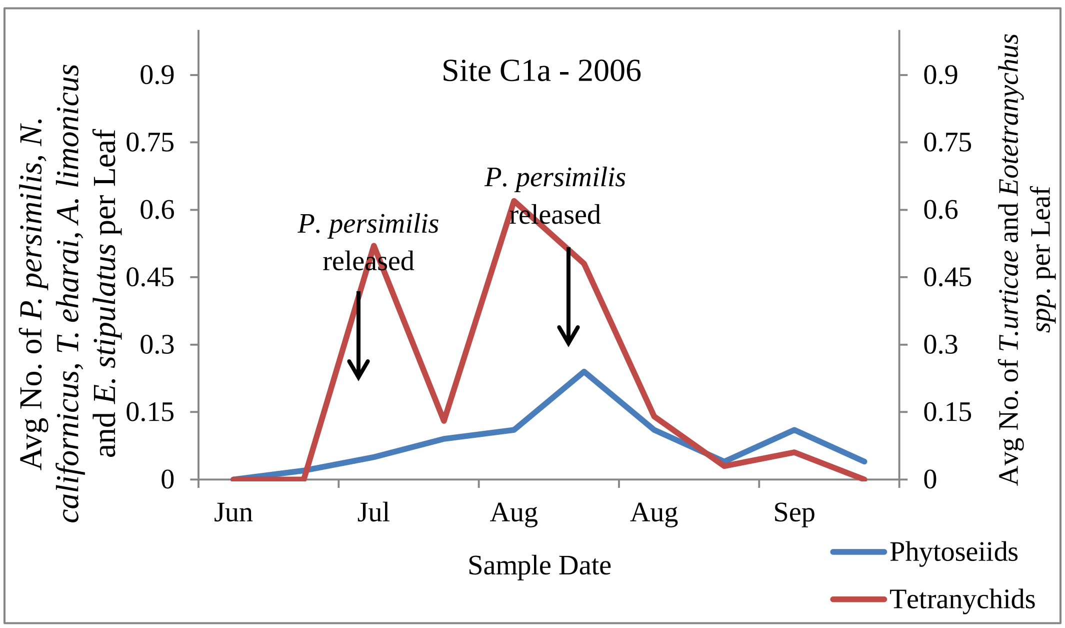

Figure 57. Average number of phytoseiids (*Phytoseiulus persimilis, Neoseiulus californicus, Typhlodromina eharai, Amblydromalus limonicus* and *Euseius stipulatus*) and tetranychids (*Tetranychus urticae* and *Eotetranychus* spp.) per leaf at C1a, 2006. *Phytoseiulus persimilis* were released on June 23 and Aug 8.

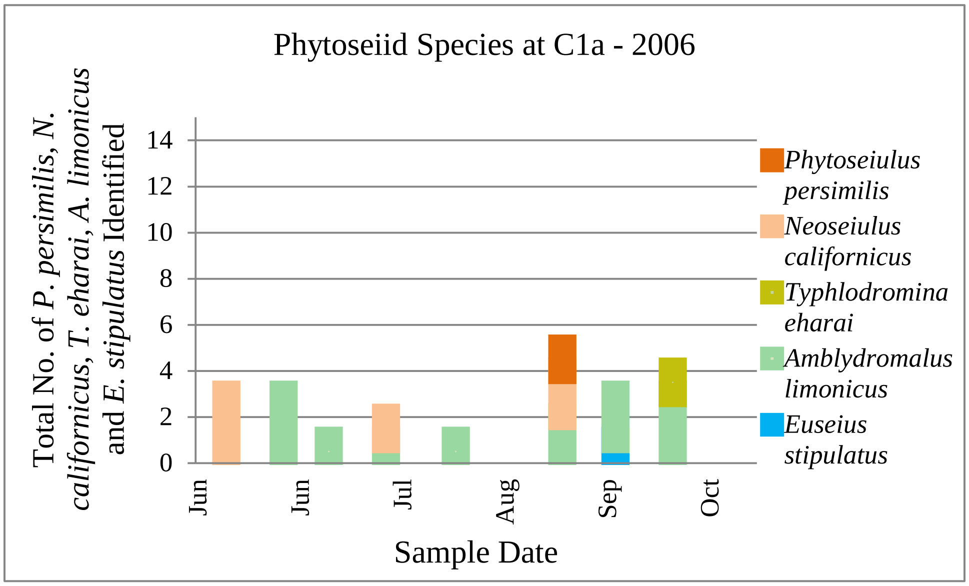

Figure 58. Total number of phytoseiids (*Phytoseiulus persimilis, Neoseiulus californicus, Typhlodromina eharai, Amblydromalus limonicus,* and *Euseius stipulatus*) slide mounted and identified at C1, 2006.

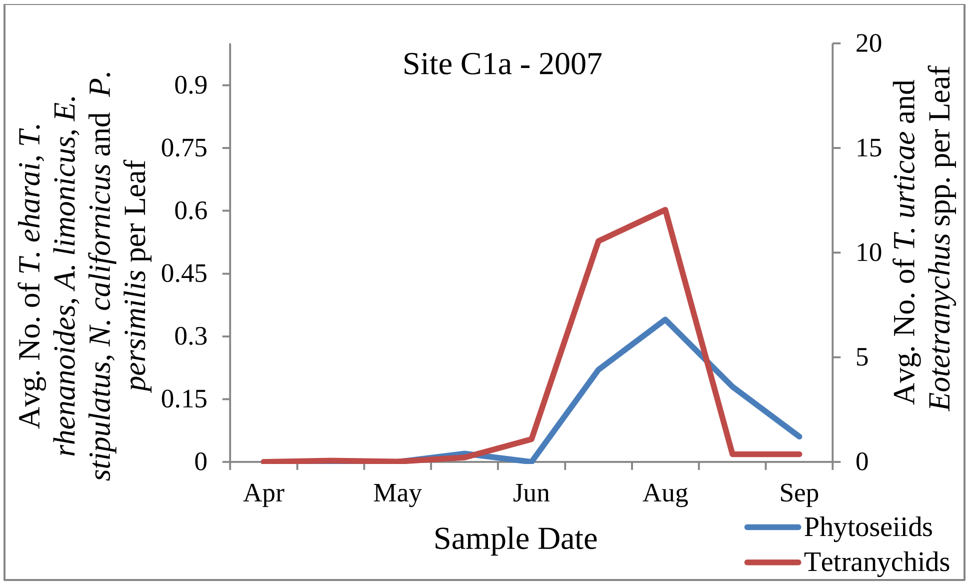

Figure 59. Average number of phytoseiids (*Typhlodromina eharai*, *Typhlodromalus rhenanoides*, *Amblydromalus limonicus*, *Euseius stipulatus*, *Neoseiulus californicus*, *Phytoseiulus persimilis*) and tetranychids (*Tetranychus urticae* and *Eotetranychus* spp.) per leaf at C1a, 2007.

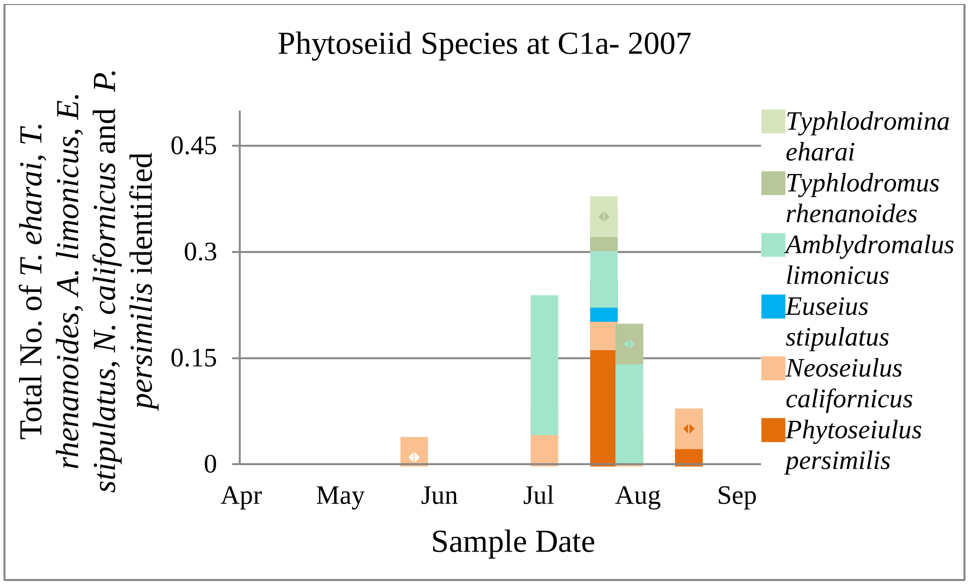

Figure 60. Total number of phytoseiids (*Typhlodromina eharai*, *Typhlodromalus rhenanoides*, *Amblydromalus limonicus*, *Euseius stipulatus*, *Neoseiulus californicus, and Phytoseiulus persimilis*) slide mounted and identified at C1, 2007.

Tetranychus urticae and *Eotetranychus* spp. peaked in July at C2-2006 with an average of 0.50 mites per leaf (Fig. 61). Phytoseiid also peaked in July with an average of 0.33 mites per leaf. Phytoseiid species collected and identified included *P. persimilis, A. limonicus*, and *E. stipulatus* (Fig. 62). This field was not samples in 2007.

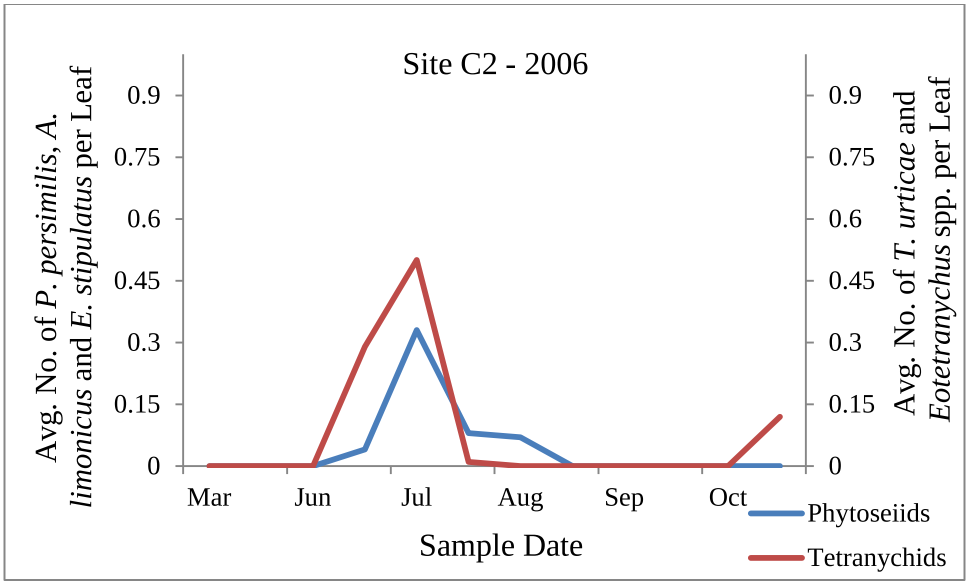

Figure 61. Average number of phytoseiids (*Phytoseiulus persimilis*, *Amblydromalus limonicus*, *Euseius stipulatus*) and tetranychids (*Tetranychus urticae* and *Eotetranychus* spp.) per leaf at C2, 2006.

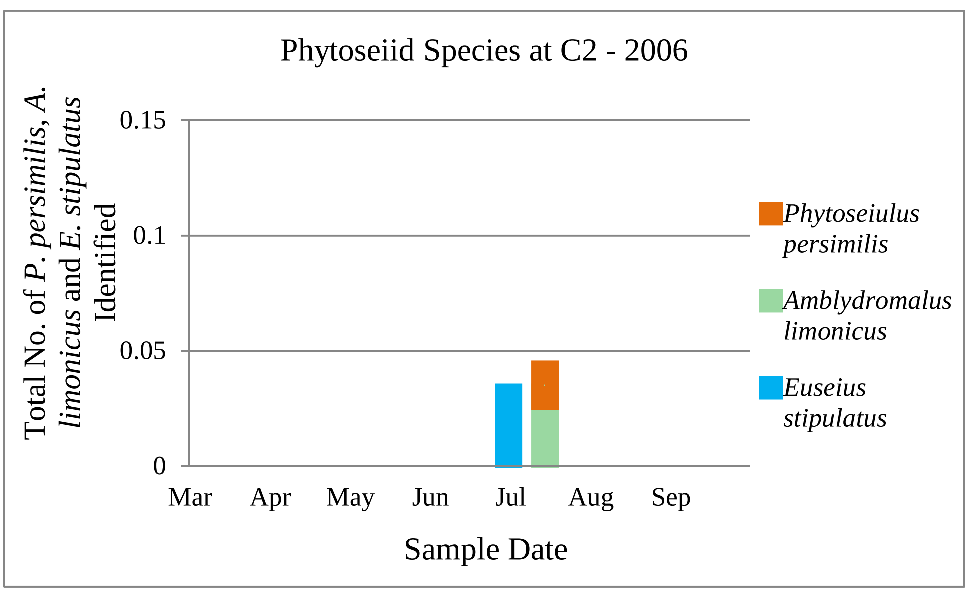

Figure 62. Total number of phytoseiids (*Phytoseiulus persimilis*, *Amblydromalus limonicus*, and *Euseius stipulatus*) slide mounted and identified at C2, 2006.

Tetranychids *T. urticae* and *Eotetranychus* spp. were present throughout the sampling season at C3-2006. Activity began in April, peaked in July, decreased through August, and resurged again later in the season in September into October (Fig. 63). Type III *A. limonicus* appeared in June and was active throughout the season (Fig. 64). Both *A. limonicus* and *P. persimilis* were most active in June and July (Fig. 64) with 0.48 mites per leaf recorded (Fig. 63). *Amblydromalus limonicus* peaked again in late August into September (Fig. 64). Many of the phytoseiids collected were not suitable for slide mounting and identification, therefore, the density of the June population is not reflected in species graph (Fig. 64). In 2007, *T. urticae* and *Eotetranychus* spp. peaked in May, June and August and declined sharply between these peaks (Fig. 65). Phytoseiids *A. limonicus*, *E. stipulatus*, *N. californicus*, and *P. persimilis* first appeared in April and were most active in late June (Fig. 66), and *P. persimilis* were released in early May (Fig. 65).

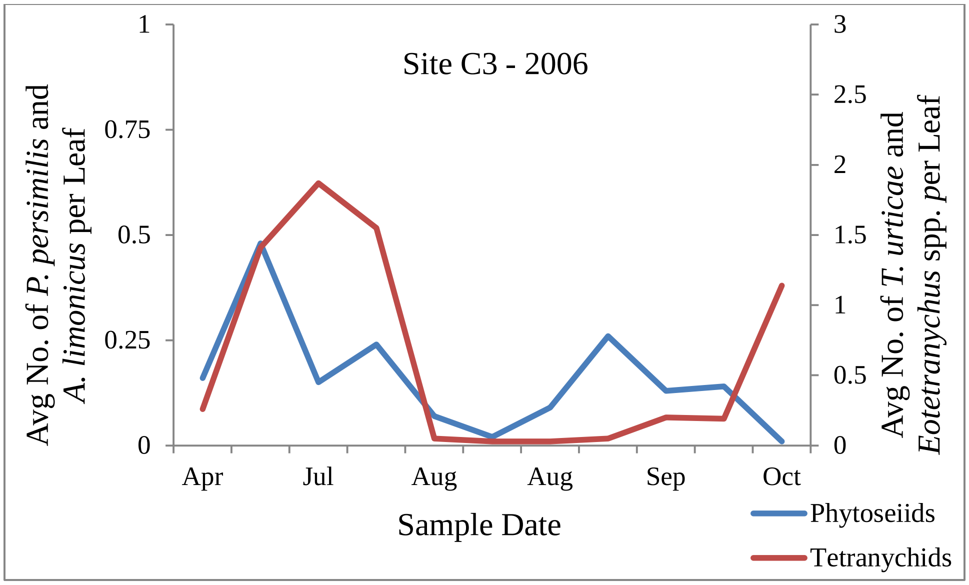

Figure 63. Average number of phytoseiids (*Phytoseiulus persimilis* and *Amblydromalus limonicus*) and tetranychids (*Tetranychus urticae* and *Eotetranychus* spp.) per leaf at C3 in 2006.

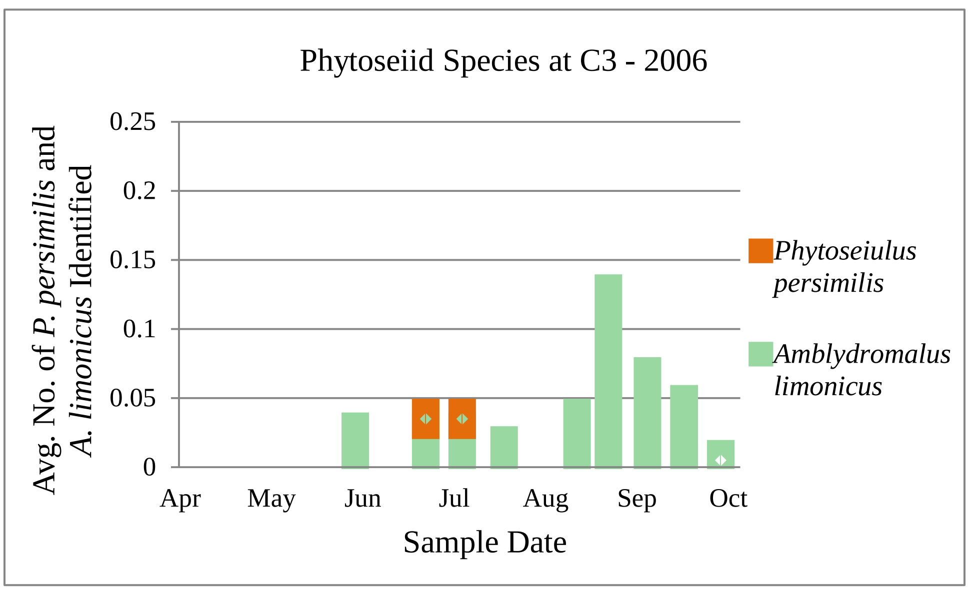

Figure 64. Total number of phytoseiids (*Phytoseiulus persimilis* and *Amblydromalus limonicus*) slide mounted and identified at C3, 2006.

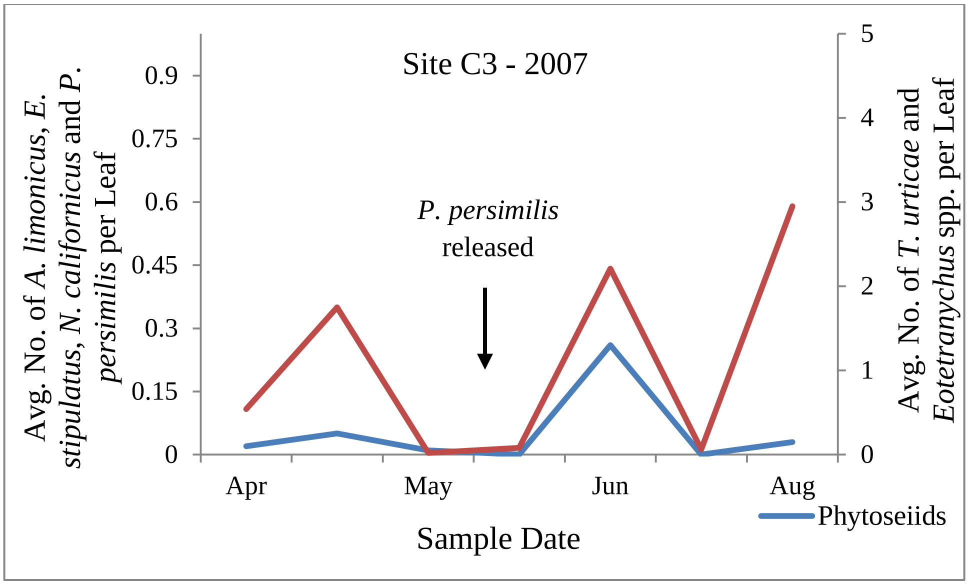

Figure 65. Average number of phytoseiids (*Amblydromalus limonicus*, *Euseius stipulatus*, *Neoseiulus californicus*, and *Phytoseiulus persimilis*) and tetranychids (*Tetranychus urticae* and *Eotetranychus* spp.) per leaf at C3, 2007. *Phytoseiulus persimilis* were released on May 10, 2007.

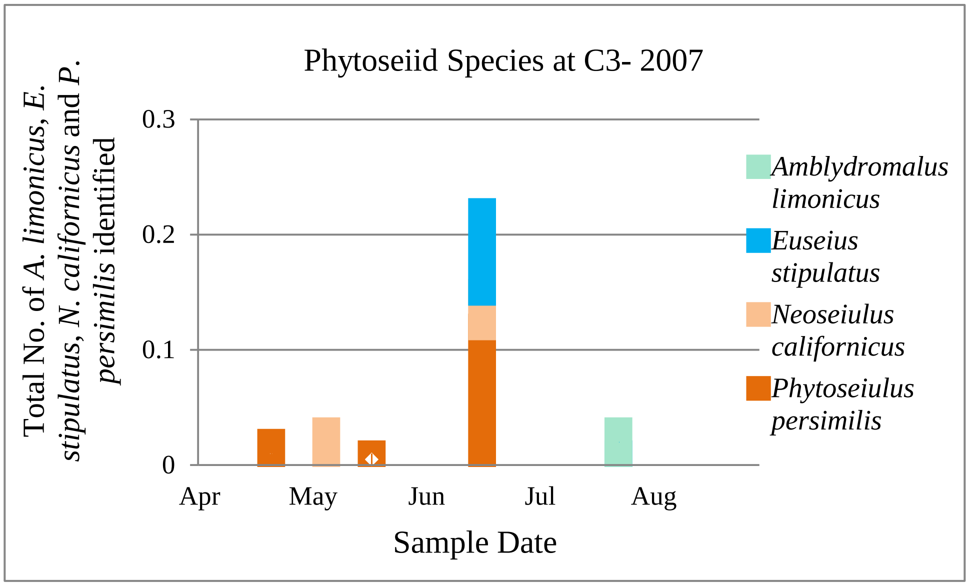

Fig. 66. Total number of phytoseiids (*Amblydromalus limonicus*, *Euseius stipulatus*, *Neoseiulus californicus*, and *Phytoseiulus persimilis*) slide mounted and identified at C3, 2007.

Tetranychus urticae and *Eotetranychus* spp. activity began in April at C4-2006 and peaked in May and June with an average of 1.4 and 3.7 mites per leaf, respectively (Fig. 67). The tetranychid population then decreased gradually through October. Phytoseiids *P. persimilis*, *N. californicus*, and *E. stipulatus* also appeared in April and peaked in June (Fig 68) with 0.2 and 0.26 mites per leaf, respectively (Fig. 67). Phytoseiid species present in late June included *P. persimilis* and *E. stipulatus* (Fig. 68). In 2007, *T. urticae* and *Eotetranychus* spp. activity peaked in late June with 1.68 mites per leaf (Fig. 69). Phytoseiids *M. johnsoni, E. stipulatus,* and *P. persimilis* were active in April and June (Fig. 70) and *P. persimilis* were released in May (Fig. 69).

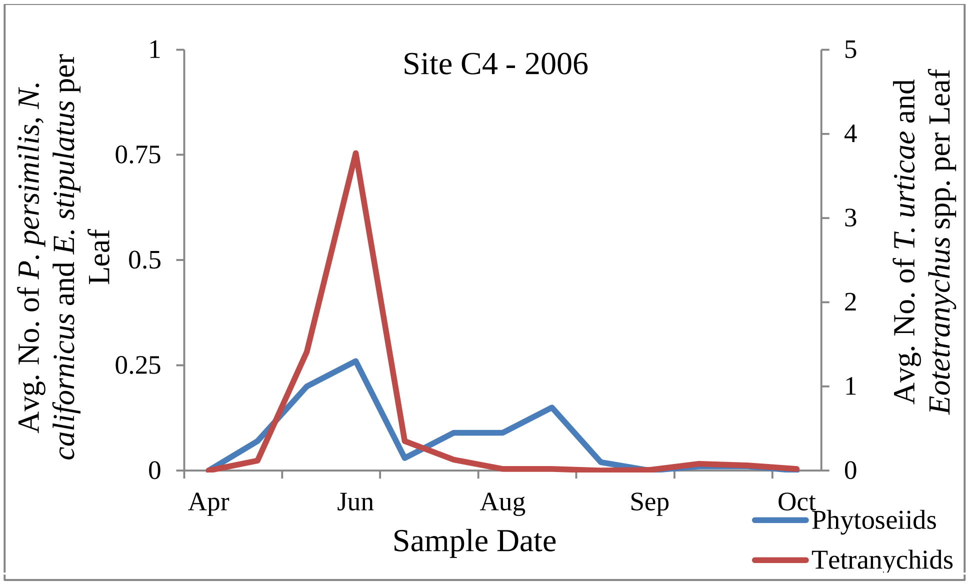

Figure 67. Average number of phytoseiids (*Phytoseiulus persimilis*, *Neoseiulus californicus*, and *Euseius stipulatus*) and tetranychids (*Tetranychus urticae* and *Eotetranychus* spp.) per leaf at C4, 2006.

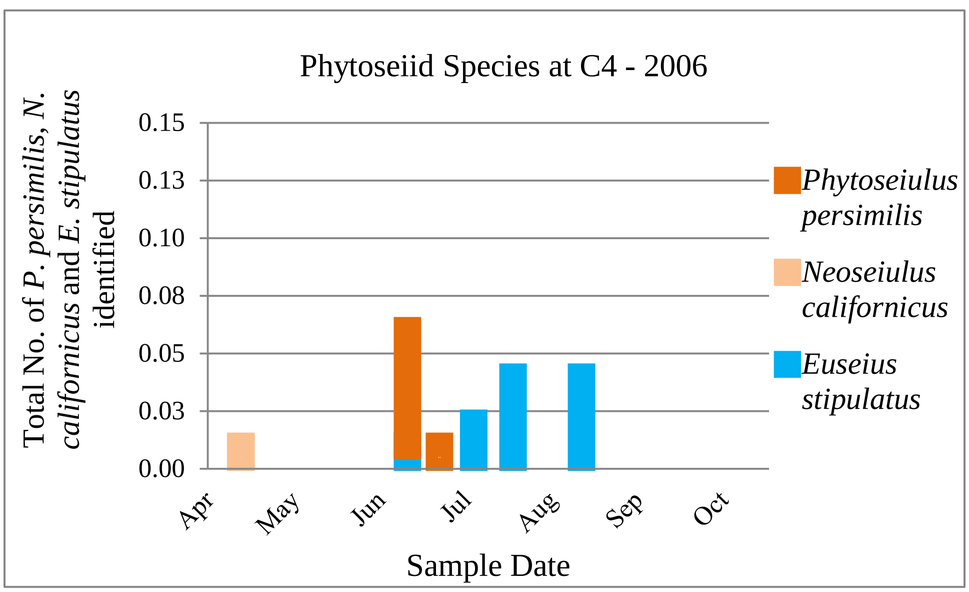

Figure 68. Total number of phytoseiids (*Phytoseiulus persimilis*, *Neoseiulus californicus*, and *Euseius stipulatus*) slide mounted and identified at C4, 2006.

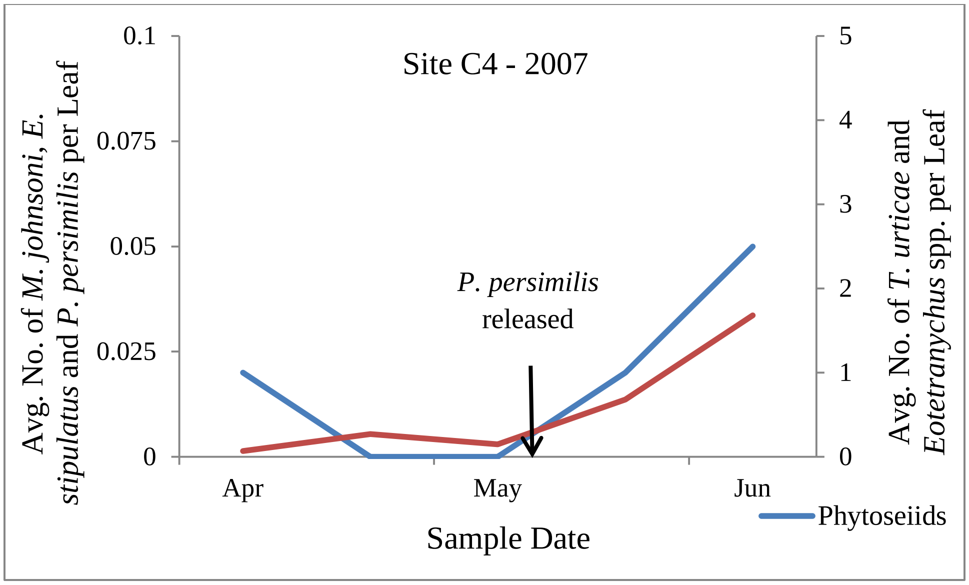

Figure 69. Average number of phytoseiids (*Metaseiulus johnsoni*, *Euseius stipulatus*, and *Phytoseiulus persimilis*) and tetranychids (*Tetranychus urticae* and *Eotetranychus* spp.) per leaf at C4, 2007. *Phytoseiulus persimilis* were release on May 10.

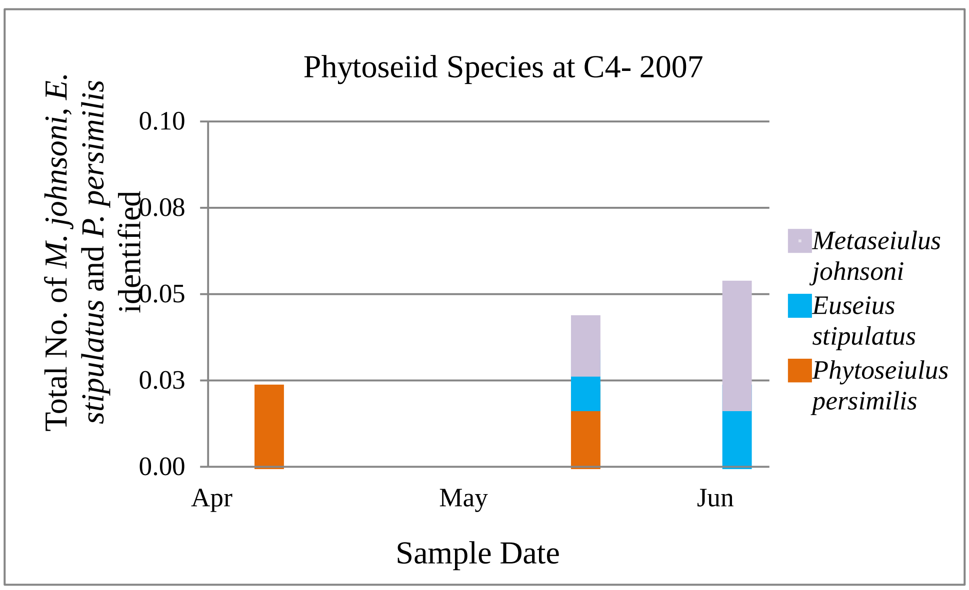

Figure 70. Total number of phytoseiids (*Metaseiulus johnsoni*, *Euseius stipulatus*, and *Phytoseiulus persimilis*) slide mounted and identified at C4, 2007.

Tetranychids *T. urticae* and *Eotetranychus* spp. were active at C5-2006 from April through July and reach an average of 0.6 mites per leaf in April and an average of 0.7 mites per leaf in July (Fig 71). The population decreased to 0 in August and appeared again in September with an average of 0.29mites per leaf (Fig. 71). Phytoseiids *M. johnsoni*, *N. californicus*, and *E. stipulatus* were most active from June through August (Fig. 72) and peaked in June with an average of 0.46 mites per leaf (Fig. 71). In 2007, *T. urticae* and *Eotetranychus* spp. peaked in May with an average of 2.6 pest mites per leaf and decreased to an average of 0.12 per leaf in June (Fig. 73). *Phytoseiulus persimilis* and *E*. *stipulatus* were active April through June (Fig. 74) and peaked in May and June with an average of 0.5 mites per leaf (Fig. 73).

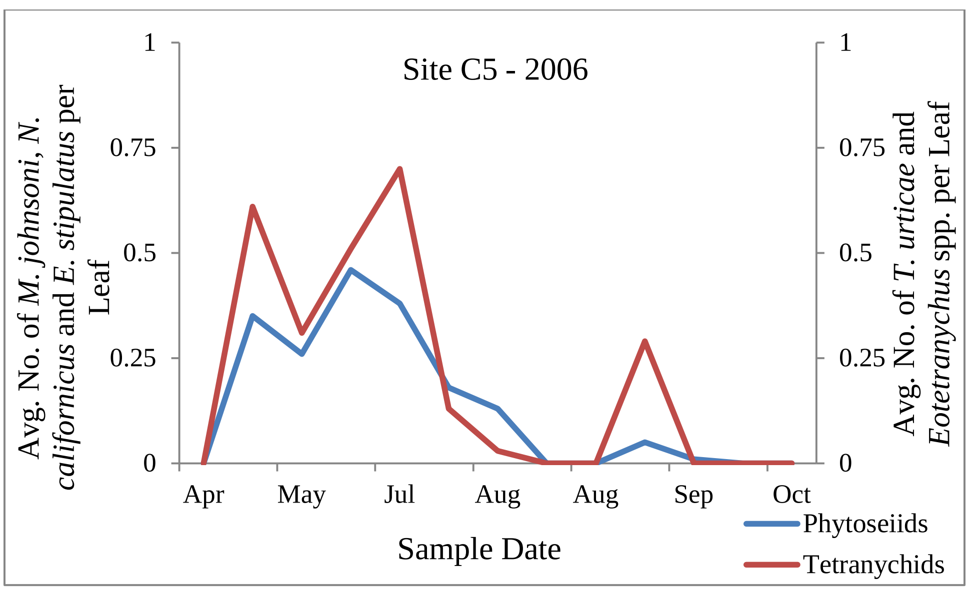

Figure 71. Average number of phytoseiids (*Metaseiulus johnsoni*, *Neoseiulus californicus*, and *Euseius stipulatus*) and tetranychids (*Tetranychus urticae* and *Eotetranychus* spp.) per leaf at C5, 2006.

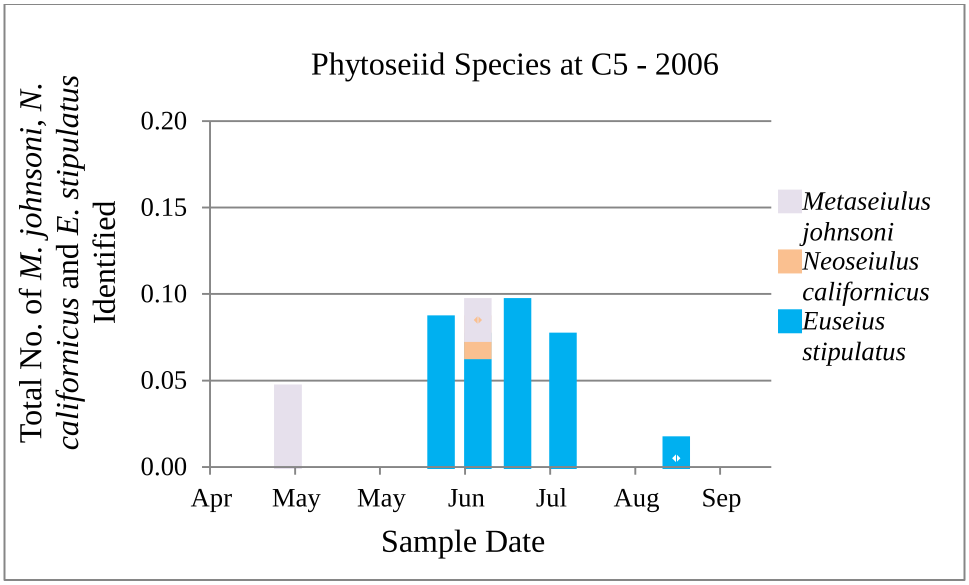

Figure 72. Total number of phytoseiids (*Metaseiulus johnsoni*, *Neoseiulus californicus*, and *Euseius stipulatus*) slide mounted and identified at C5, 2006.

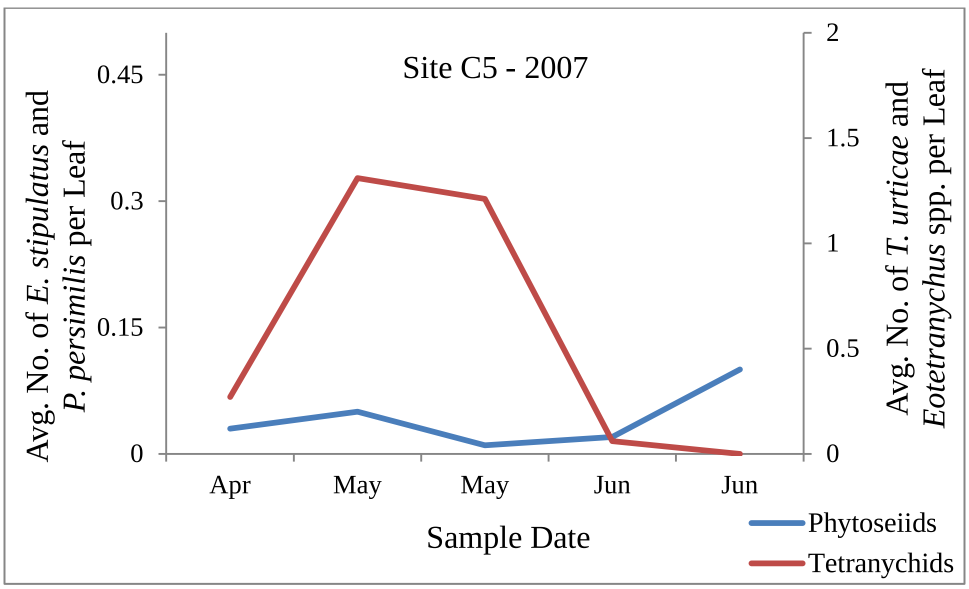

Figure 73. Average number of phytoseiids (*Euseius stipulatus* and *Phytoseiulus persimilis*) and tetranychids (*Tetranychus urticae* and *Eotetranychus* spp.) per leaf at C5, 2007.

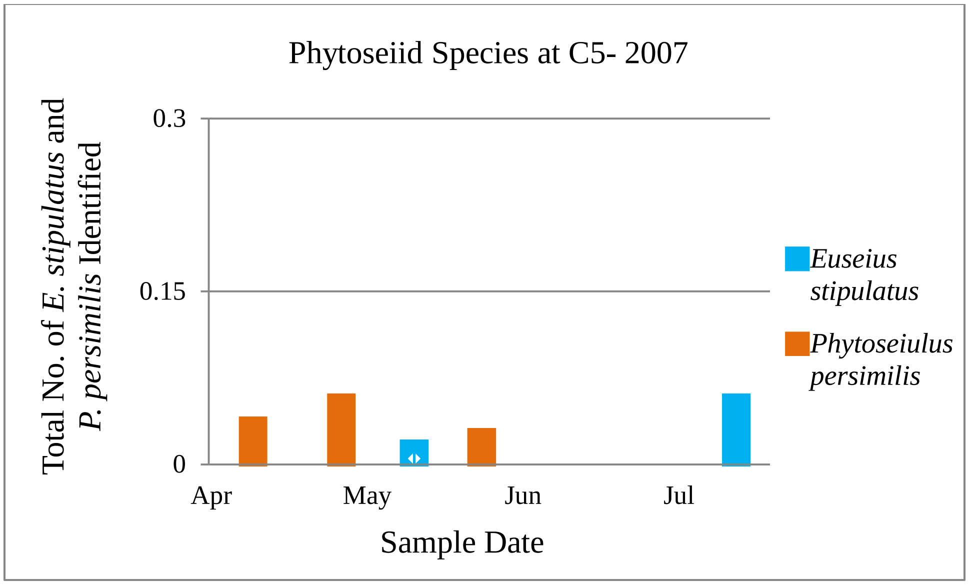

Figure 74. Total number of phytoseiids (*Euseius stipulatus* and *Phytoseiulus persimilis*) slide mounted and identified at C5, 2007.

Blackberry

The average number of phytoseiids counted per leaf was 7 times greater in 2006 than in 2007 on blackberry at site C1 (Table 15). The average number of tetranychids was 25.7 times greater in 2007 than in 2006

Table 15. Average number of phytoseiids and tetranychids counted per leaf on blackberry, 2006 and 2007.

		Average Phytoseiid and Tetranychid Mites Counted per Leaf	
Year	Field Site	*Phytoseiidae*	*Tetranychidae*
2006	C1b	0.14	0.25
2007	C1b	0.02	6.42

Neoseiulus californicus made up 48% and 25% of the total phytoseiids species identified on blackberry in 2006 and 2007, respectively (Table 16). *Galendromus annectans* (24.5%), *G. occidentalis* (14.3%), *T. eharai* (8.2%), and *A. limonicus* (5.1%) followed in 2006. Both *A limonicus* and *N. californicus* made up 25% of the total phytoseiids collected and identified in 2007, followed by *E. stipulatus* (12.5%), *T. eharai* (12.5%), *M. arboreus* (12.5%), and *M. johnsoni* (12.5%). *Tetranychus urticae* and *Eotetranychus* spp. were present both seasons and site identified in the field.

Table 16. Phytoseiids identified on blackberry, 2006 and 2007.

Year	Field Site	Phytoseiidae							
		Euseius stipulatus	*Amblydromalus limonicus*	*Typhlodromina eharai*	*Metaseiulus arboreus*	*Metaseiulus johnsoni*	*Galendromus annectans*	*Galendromus occidentalis*	*Neoseiulus californicus*
Type		Type IV	Type III	Type III	Type III	Type III	Type II	Type II	Type II
2006	C1b	0	5 (5.1%)	8 (8.2%)	0	0	24 (24.5%)	14 (14.3%)	47 (48.0%)
2007	C1b	1(12.5%)	2 (25%)	1 (12.5%)	1 (12.5%)	1 (12.5%)	0	0	2 (25%)
Total		1 (0.9%)	7 (6.6%)	9 (8.5%)	1 (0.9%)	1 (0.9%)	24 (22.6%)	14 (13.2%)	49 (46.2%)

Tetranychus urticae and *Eotetranychus* spp. activity peaked in April at C1 on blackberry with an average of 1.9 mites per leaf then decreased through the rest of the season (Fig. 75). Phytoseiids *N. californicus, G. occidentalis, G. annectans, T. eharai*, and *A. limonicus* peaked in April (Fig. 76) with an average of 0.7mites per leaf and *Phytoseiulus persimilis* were released in June and August (Fig. 75). In 2007, *T. urticae* and *Eotetranychus* spp. activity began in April and peaked in May with an average of 34.2 mites per leaf and a secondary peak in June with an average of 11.0 mites per leaf in June (Fig. 77). Phytoseiids *A. limonicus*, *N. californicus*, *T. eharai*, *M. arboreus*, *M. johnsoni*, and *E. stipulatus* were active June through August (Fig. 78) and peaked in June and August with an average of 0.04 mites per leaf (Fig. 77).

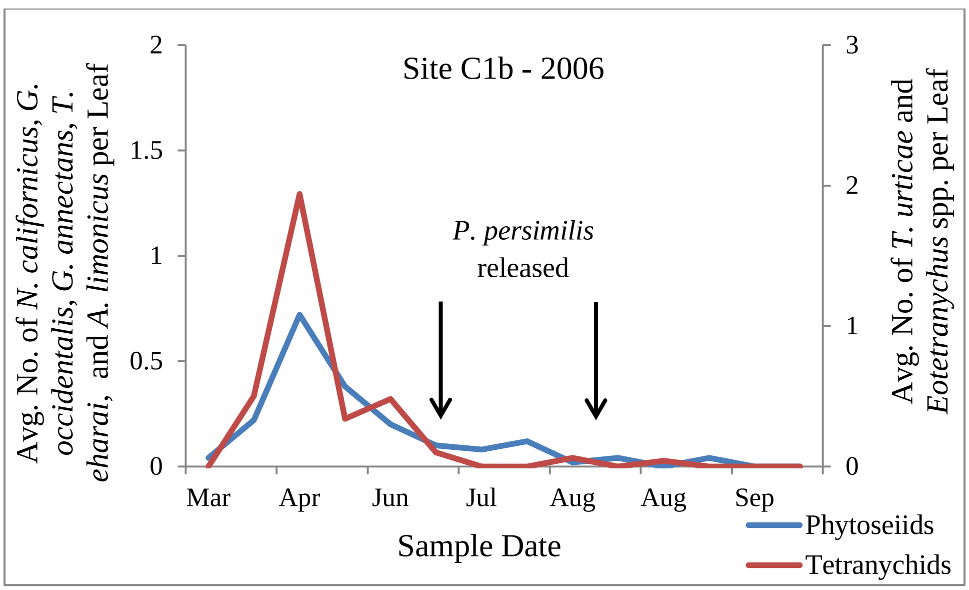

Figure 75. Average number of phytoseiids (*Neoseiulus californicus*, *Galendromus occidentalis*, *Galendromus annectans*, *Typhlodromina eharai*, and *Amblydromalus limonicus*) and tetranychids (*Tetranychus urticae* and *Eotetranychus* spp.) per leaf at C1, 2006. *Phytoseiulus persimilis* were released on June 23 and Aug 8.

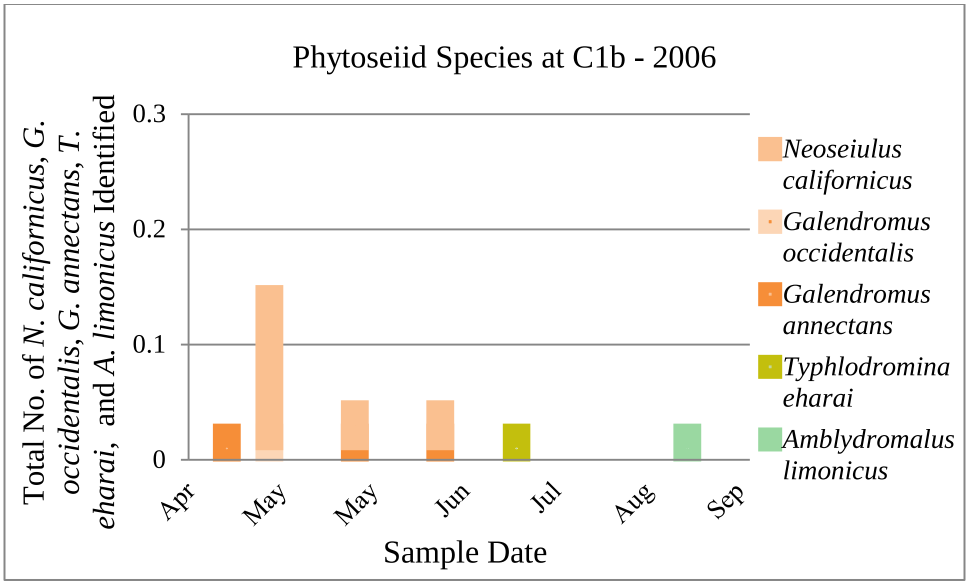

Figure 76. Total number of phytoseiids (*Neoseiulus californicus*, *Galendromus occidentalis*, *Galendromus annectans*, *Typhlodromina eharai*, and *Amblydromalus limonicus*) slide mounted and identified at C1b, 2006.

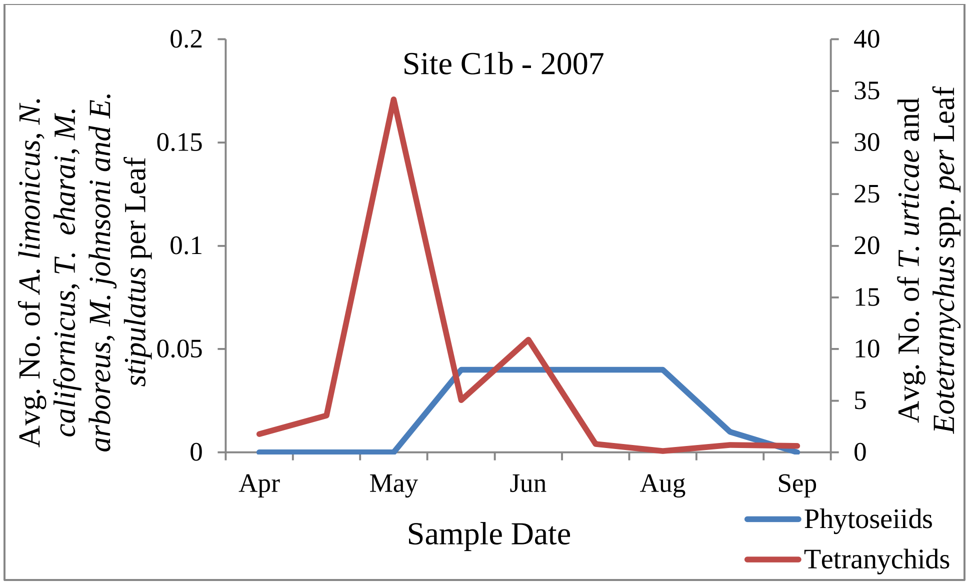

Figure 77. Average number of phytoseiids (*Amblydromalus limonicus*, *Neoseiulus californicus*, *Typhlodromina eharai*, *Metaseiulus arboreus*, *Metaseiulus johnsoni*, and *Euseius stipulatus*) and tetranychids (*Tetranychus urticae* and *Eotetranychus* spp.) per leaf at C1b, 2007.

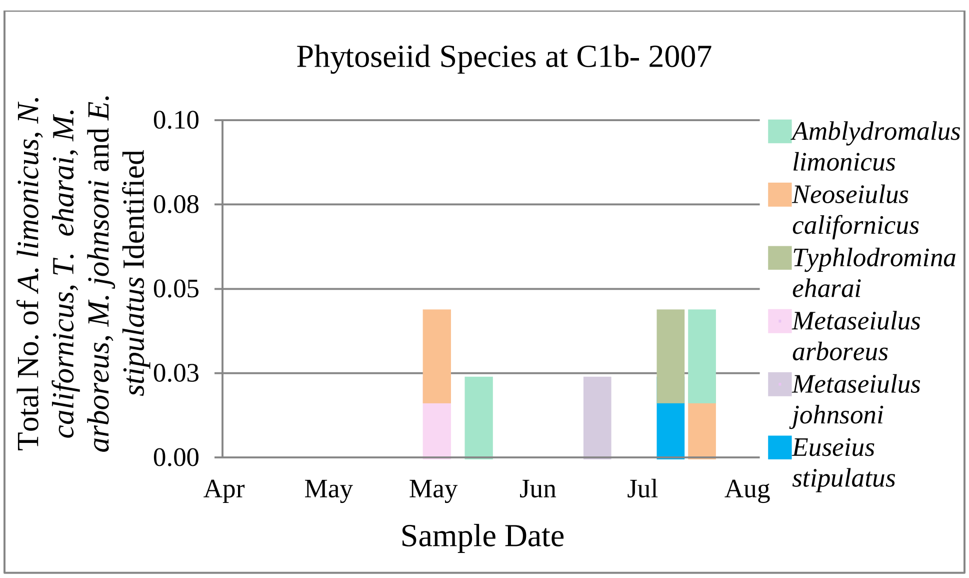

Fig. 78. Total number of phytoseiids (*Amblydromalus limonicus*, *Neoseiulus californicus*, *Typhlodromina eharai*, *Metaseiulus arboreus*, *Metaseiulus johnsoni*, and *Euseius stipulatus*) slide mounted and identified at C1b, 2007.

There were 11 collection dates total for caneberry over the two seasons. Of those, four demonstrated a pest-predator relationship (Figs. 61, 65, 75 and 77). The remainder showed phytoseiid populations that did not respond to the tetranychids, suggesting a preference for a different food source (Figs. 57, 67 and 73). The survey of raspberry and blackberry drew a similar degree of diversity of phytoseiid species (Tables 14 and 16). More specifically, site C1, with both raspberry and blackberry crops, had the most diverse collection of phytoseiids. When present, *P. persimilis*, *N. californicus* and *G. occidentalis*, *M. Johnson* and *M. arboreus* appeared to provide a level of management of pest mites, as their presence resulted in a decline of *T. urticae* and *Eotetranychus* spp.

Distribution Pattern

The three most abundant species in 2006 were types II, III and IV. Type II was expected to aggregate and types III and IV were expected to have a random distribution. Sites C2 and C4 both showed a regular distribution (Table 17). All but one population of tetranychids showed a random distribution pattern.

Table 17. Statistical findings for caneberry, 2006 and 2007. The scale used to determine the CD: < 0.90 = regular; 0.90-1.10 = random; > 1.10 = aggregated.

				Poisson Regression			
Crop/site	Year	Phytoseiids	Tetranychids	P-value		% of deviance	
Caneberry (Raspberry)	2006			P	T	P	T
C1a		0.88 Regular	0.91 Random	0.0000	0.0000	99.55%	99.68%
C2		0.96 Random	0.96 Random	0.0000	0.0000	99.96%	99.99%
C3		0.87 Regular	0.86 Regular	0.0000	0.0000	99.46%	99.07%
C4		0.94 Random	0.93 Random	0.0000	0.0000	99.98%	99.96%
C5		0.90 Random	0.92 Random	0.0000	0.0000	99.66%	99.78%
(Blackberry)	2006						
C1b		0.90 Random	0.91 Random	0.0000	0.0000	99.65%	99.64%
(Raspberry)	2007						
C1a		0.92 Random	1.69 Aggregated	0.0000	0.0000	99.82%	99.68%
C3		0.94 Random	0.89 Regular	0.0000	0.0000	99.89%	98.37%
C4		0.98 Random	0.80 Regular	0.0000	0.0000	99.98%	98.58%
C5		0.96 Random	0.97 Random	0.0000	0.0000	99.95%	99.67%
(Blackberry)	2007						
C1b		0.97 Random	6.43 Aggregated	0.0000	0.0000	99.97%	90.71%

<u>Grape</u>

The average number of phytoseiids per leaf on grape in 2006 was 6 times greater than in 2007 (Table 18). The average number of tetranychids was nearly the same in 2006 and 2007 with 0.21 and 0.20 mites per leaf, respectively.

Table 18. Average number of phytoseiids and tetranychids per leaf on grape, 2006 and 2007.

		Average Phytoseiid and Tetranychid Mites Counted per Leaf	
Year	Field Site	*Phytoseiidae*	*Eotetranychus willamettei* and *Tetranychus urticae*
2006			
	G1	0.0	0.84
	G2	0.03	0.10
	G3	0.01	0.0
	G4	0.8	0.01
	G5	0.07	0.09
Season Avg.		0.18	0.21
2007	G2	0.01	0.00
	G4	0.04	0.02
	G5	0.04	0.76
	G6	0.03	0.02
Season Avg.		0.03	0.2

Euseius quetzali was the dominant phytoseiid identified on grape in 2006 with 51.5% of the total, followed by *E. stipulatus* (19.1%), *E. hibisci* (8.8%), and *P. persimilis* (7.4%) (Table 18). *Euseius stipulatus* was the most prominent species identified in 2007 with 38.9% of the total followed by *M. flumenis* (16.7%), *E. quetzali* (11.1%), *A. similoides* (11.1%) (Table 18). Tetranychids *E. willamettei* and *T. urticae* were site identified in the field.

Table 19. Phytoseiid species identified on grape, 2006 and 2007.

		Phytoseiidae						
Year	Field Site	*Euseius stipulatus*	*Euseius hibisci*	*Euseius quetzali*	*Euseius tularensis*	*Amblyseius similoides*	*Typhlodromu s rhenanoides*	*Metaseiulus citri*
Type		Type IV	Type IV	Type IV	Type IV	Type III	Type III	Type III
2006	G2	9	0	0	0	0	0	0
	G1	0	0	0	0	0	0	0
	G3	0	0	0	0	0	0	0
	G4	3	5	17	0	0	0	2
	G5	1	1	18	1	0	0	0
Total		13 (19.1%)	6 (8.8%)	35 (51.5%)	1 (1.5%)	0	0	2 (2.9%)
2007	G2	2	0	0	0	1	1	0
	G6	25	0	2	0	0	0	0
	G4	1	4	6	0	0	0	2
	G5	0	0	0	0	0	0	3
Total		28 (38.9%)	4 (5.6%)	8 (11.1%)	0	1 (1.5%)	1 (1.4%)	5 (6.9%)

Table 19. Phytoseiid species identified at each vineyard, 2006 and 2007, continued.

Year	Field Site	Phytoseiid Species				
		Metaseiulus flumenis	*Metaseiulus johnsoni*	*Galendromus occidentalis*	*Neoseiulus aurescens*	*Phytoseiulus persimilis*
Type		Type III	Type III	Type II	Type II	Type 1
2006	G2	0	0	0	0	5
	G1	0	0	0	0	0
	G3	2	0	0	1	0
	G4	0	0	0	0	0
	G5	2	1	0	0	0
Total		4 (5.9%)	1 (1.5%)	0	0	5 (7.4%)
2007	G2	0	0	3	1	0
	G6	0	0	0	1	0
	G4	2	0	0	0	0
	G5	10	0	0	0	1
Total		12 (16.7%)	0	3 (4.2%)	2 (2.8%)	1 (1.4%)

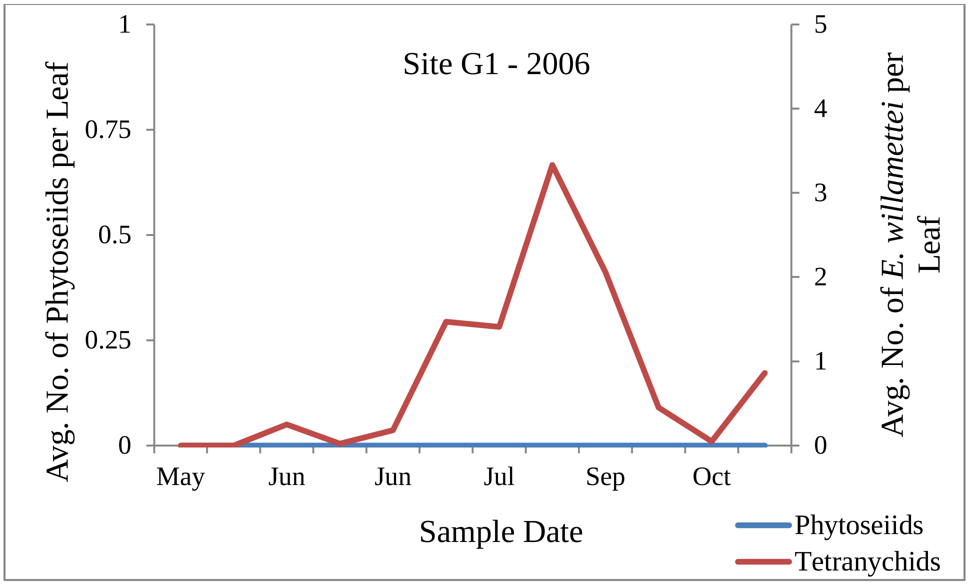

Figure 79. Average number of tetranychids (*Eotetranychus willamettei)* per leaf at G1, 2006.

Eotetranychus willamettei was active at G1-2006 from June through October and peaked in August with an average of 3.3 mites per leaf (Fig. 79). Phytoseiids were not found at this site in 2006 and sampling did continue in 2007.

Tetranychus urticae and *E. willamettei* were most active at G2-2006 from June through September, and peaked in June with an average of 0.44 mites per leaf (Fig. 80). *Phytoseiulus persimilis* appeared in June (Fig. 81) with an average of 0.03 mites per leaf, then again in September along with *E. stipulations* which peaked with an average of 0.03 mites per leaf (Fig. 80). Two applications of Stylet-Oil were applied in May to manage *T. urticae*, *E. willamettei,* and obscure mealybug, and 7 applications of spray sulfur were applied for powdery mildew between May and July (Table 4). In 2007, *E. willamettei* was present in July only (Fig. 82). Phytoseiids *T. perigrimus*, *A. similoides*, *M. johnsoni*, and

E. stipulatus were active in July and August, and peaked in September (Fig. 83) with 0.03 mites per leaf (Fig. 82). Pesticide applications included Stylet Oil to manage *E. willamettei and obscure mealybug*, Applaud and Venom for *E. willamettei*, grape leafhopper, and obscure mealybug, and Quintec and Microthiol Disperss for powdery mildew (Table 4).

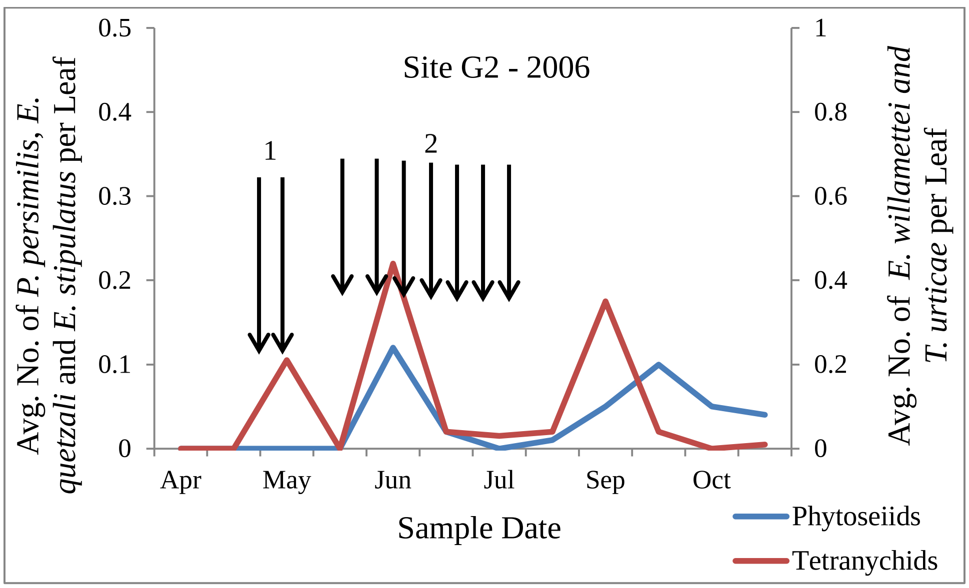

Figure 80. Average number of number of phytoseiids (*Phytoseiulus persimilis*, *Euseius quetzali*, *Euseius stipulatus*) and tetranychids (*Tetranychus urticae* and *Eotetranychus willamettei)* per leaf at G2-2006 and the insecticides applied: 1 – Stylet Oil; 2 – Spray Sulfur.

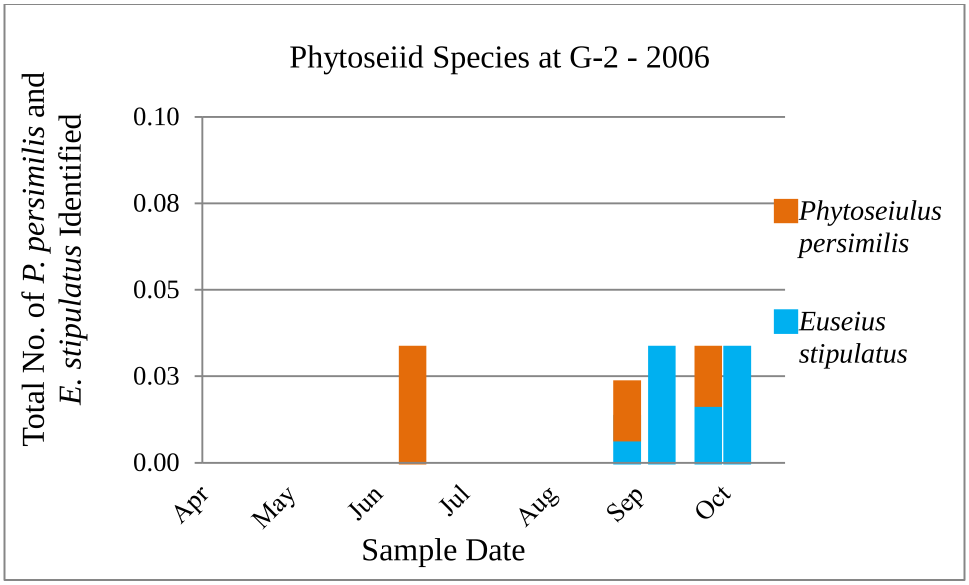

Figure 81. Total number of number of phytoseiids (*Phytoseiulus persimilis* and *Euseius stipulatus*) slide mounted and identified at G2, 2006.

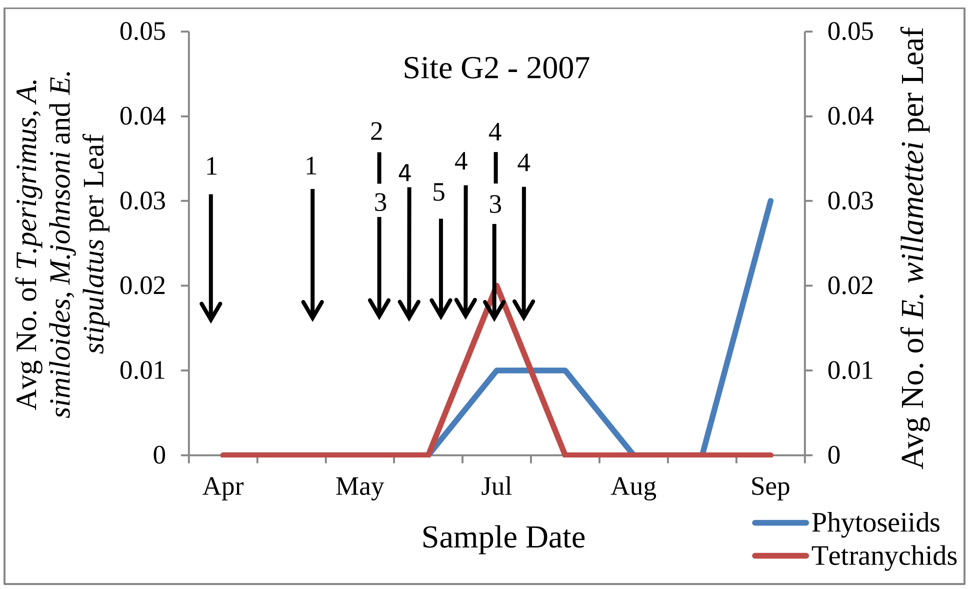

Figure 82. Average number of phytoseiids (*Typhlodromalus perigrimus*, *Amblyseius similoides*, *Metaseiulus johnsoni*, *Euseius stipulatus*) and tetranychids (*Eotetranychus willamettei*) per leaf at G2-2007 and the insecticides applied – 1 -Stylet Oil, 2 - Quintec, 3 - Applaud, 4 - Microthiol Disperss, 5 - Venom Insecticide.

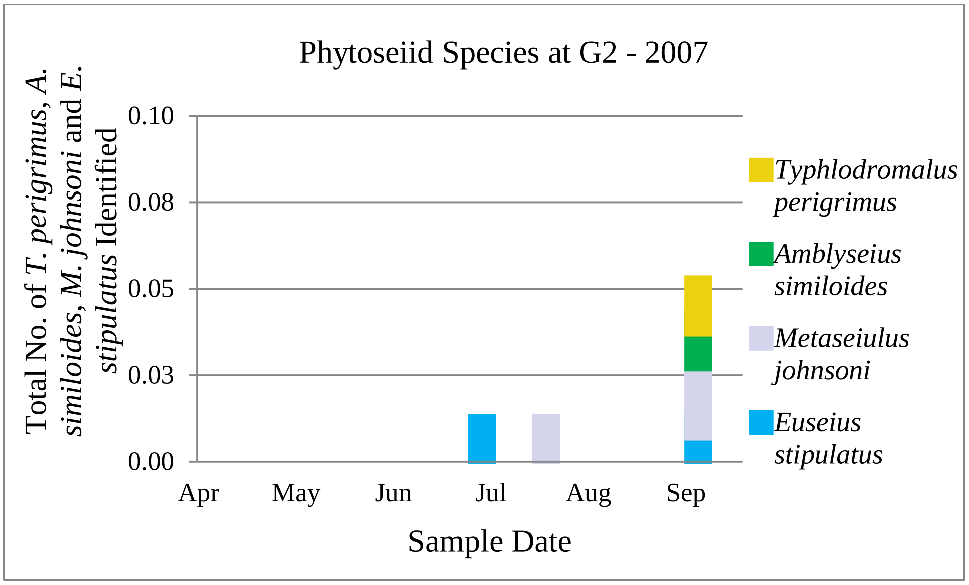

Figure 83. Total number of phytoseiids (*Typhlodromalus perigrimus*, *Amblyseius similoides*, *Metaseiulus johnsoni*, and *Euseius stipulatus*) slide mounted and identified at G2, 2007.

Tetranychids were not located at G3-2006 and a total of three *N. californicus* and *M. flumenis* were collected, the fewest for the season in Ventura County (Fig. 84). This site was not sampled in 2007.

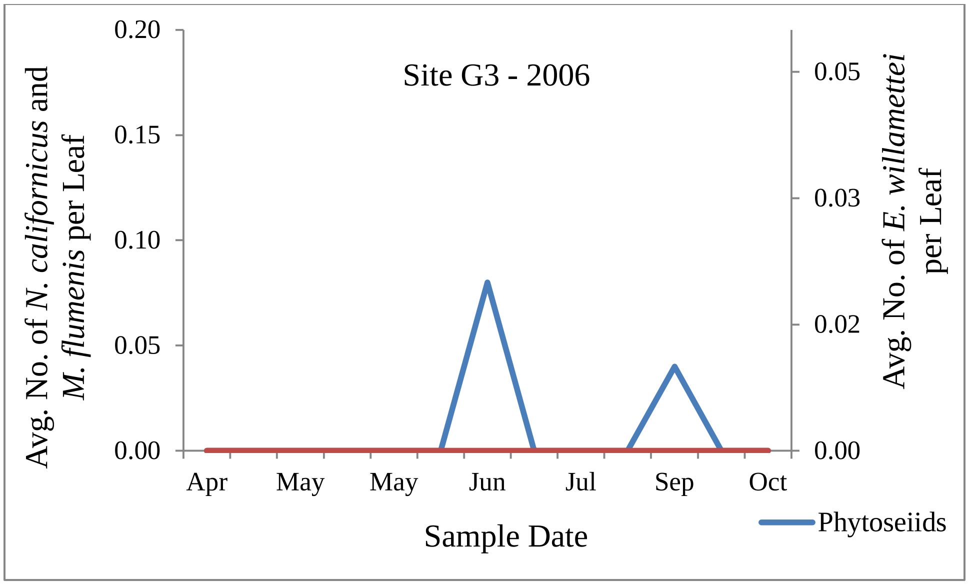

Figure 84. Average number of phytoseiids (*Neoseiulus californicus* and *Metaseiulus flumenis*) and tetranychids (*Eotetranychus willamettei*) per leaf at G3, 2006.

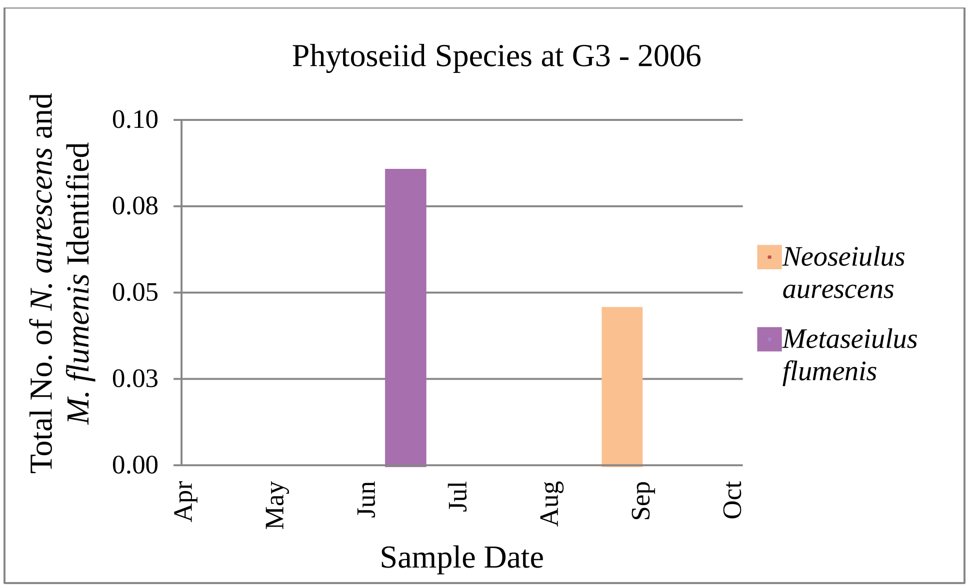

Figure 85. Total number of phytoseiids (*Neoseiulus aurescens* and *Metaseiulus flumenis*) slide mounted and identified at G3, 2006.

Tetranychus urticae and *E. willamettei* were active at G4-2006 in April, June, July and October, and peaked in June with an average of 0.06 mites per leaf (Fig. 86). Phytoseiids *M. citri*, *E. hibisci*, *E. quetzali*, and *E. stipulatus* were active from June through October (Fig. 87) and peaked in July with an average of 0.34 mites per leaf (Fig. 86). In 2007, *E. willamettei* was active in August only and peaked with an average of 0.18 mites per leaf (Fig. 88). Phytoseiids *M. citri*, *M. flumenis*, *E. hibisci*, *E. quetzali*, and *E. stipulatus* were present in July, August and September and peaked in August (Fig. 89) with an average of 0.2 mites per leaf (Fig. 88).

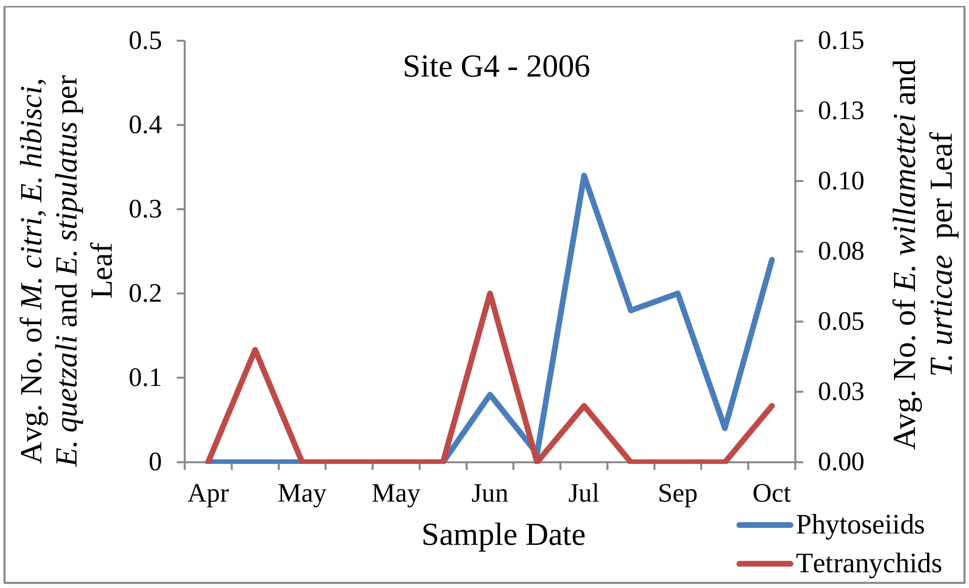

Figure 86. The average number of phytoseiids (*Metaseiulus citri*, *Euseius hibisci*, *Euseius quetzali*, *Euseius stipulatus*) and tetranychids (*Tetranychus urticae* and *Eotetranychus willamettei*) per leaf at G4 in 2006.

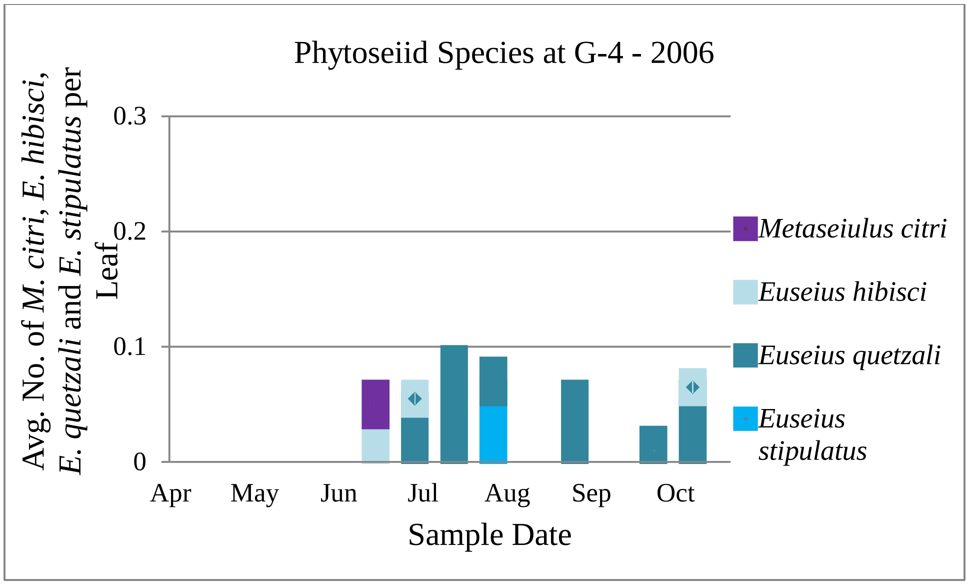

Figure 87. Total number of phytoseiids (*Metaseiulus citri*, *Euseius hibisci*, *Euseius quetzali*, and *Euseius stipulatus*) slide mounted and identified at G4, 2006.

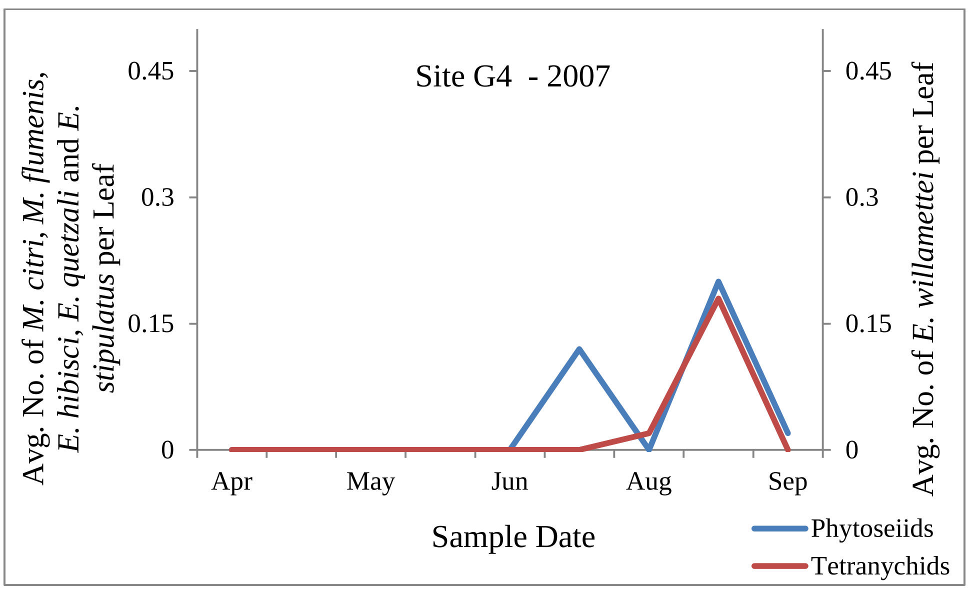

Figure 88. Average number of phytoseiids (*Metaseiulus citri*, *Metaseiulus flumenis*, *Euseius hibisci*, *Euseius quetzali*, *Euseius stipulatus*) and tetranychids (*Eotetranychus willamettei)* per leaf at G4, 2007.

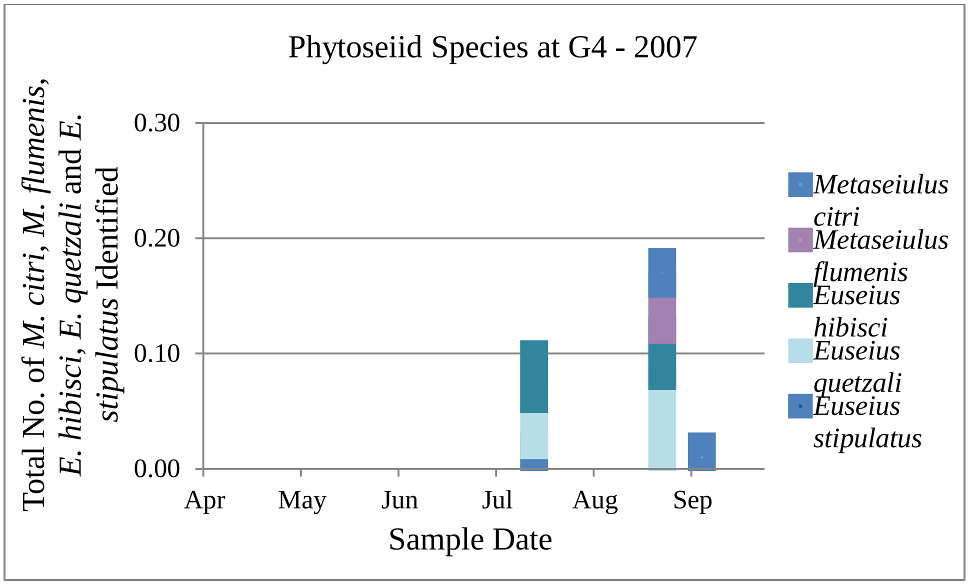

Figure 89. Total number of phytoseiids (*Metaseiulus citri*, *Metaseiulus flumenis*, *Euseius hibisci*, *Euseius quetzali*, and *Euseius stipulatus*) slide mounted and identified at G4, 2007.

Eotetranychus willamettei was most active at G5-2006 from July through October and peaked in August with an average of 0.36 mites per leaf (Fig. 90). Phytoseiids *M. flumenis*, *E. tularensis*, *E. hibisci*, *E. quetzali*, and *E. stipulatus* were active June through October (Fig. 91) and peaked in July with an average of 0.44 mites per leaf (Fig. 90). In 2007, *E. willamettei* was found on each sampling date, from April through September and the population peaked in September with an average of 2.6 mites per leaf (Fig. 92). Phytoseiids *M. citri*, *M. flumenis*, *G. occidentalis*, and *P. persimilis* were active June through September (Fig. 93) and also peaked in September with an average of 0.09 mites per leaf (Fig. 92).

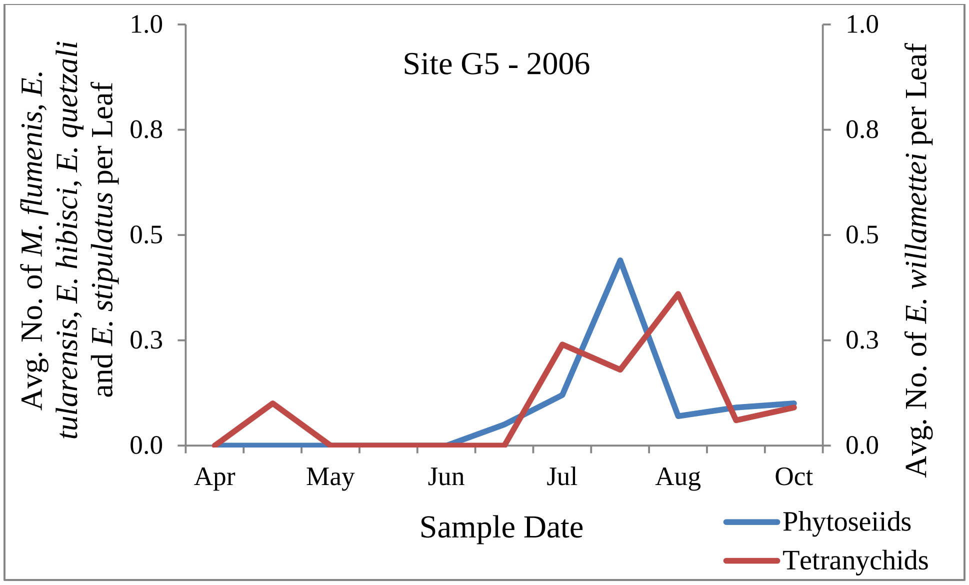

Figure 90. Average number of phytoseiids (*Metaseiulus flumenis*, *Euseius tularensis*, *Euseius hibisci*, *Euseius quetzali*, *Euseius stipulatus*) and tetranychids (*Eotetranychus. willamettei*) per leaf at G5, 2006.

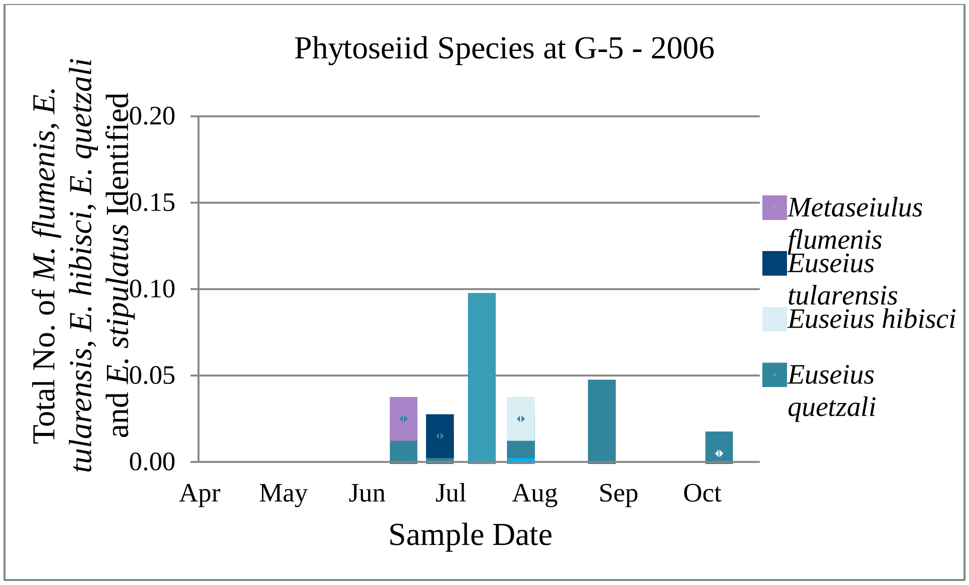

Figure 91. Total number of phytoseiids (*Metaseiulus flumenis, Euseius tularensis, Euseius hibisci*, *Euseius quetzali*, and *Euseius stipulatus*) slide mounted and identified at G5, 2006.

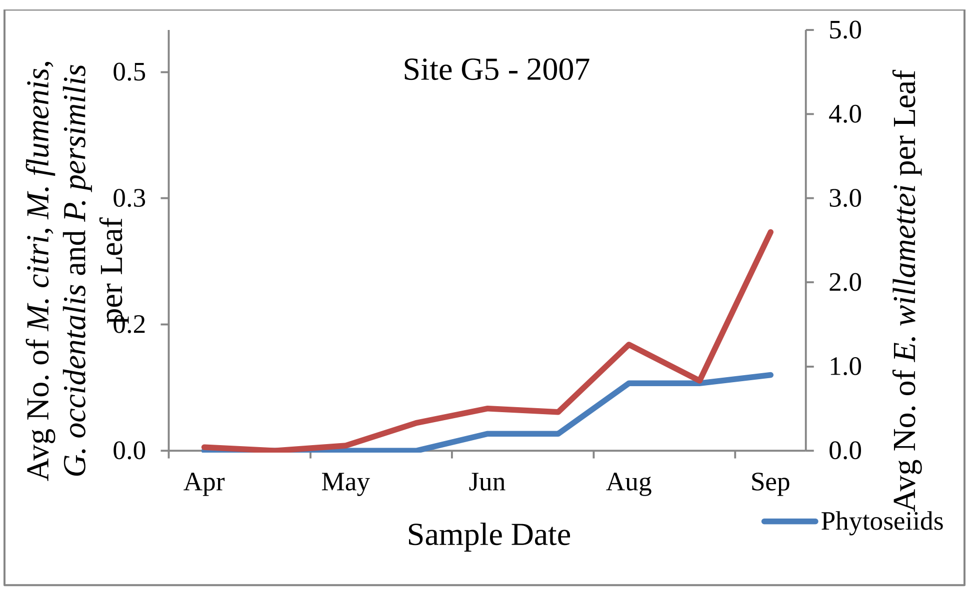

Figure 92. Average number of phytoseiids (*Metaseiulus citri*, *Metaseiulus flumenis, Galendromus occidentalis, Phytoseiulus persimilis*) and tetranychids (*Eotetranychus willamettei*) per leaf at G5, 2007.

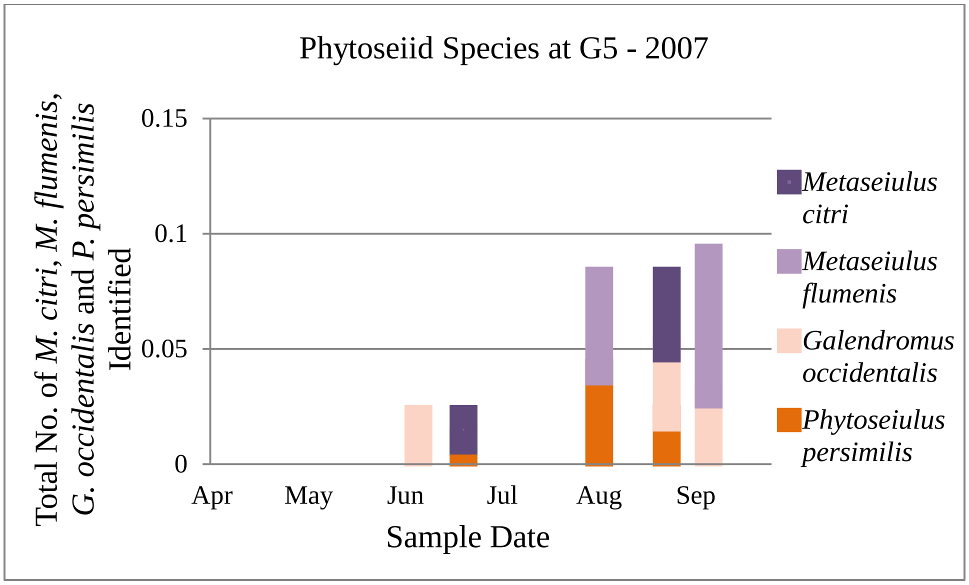

Figure 93. Total number of phytoseiids (*Metaseiulus citri*, *Metaseiulus flumenis*, *Galendromus occidentalis*, and *Phytoseiulus persimilis*) slide mounted and identified at G5, 2007.

Eotetranychus willamettei was present with an average of 0.01 mites per leaf from May through July at G6-2007(Fig. 94). The population rebounded in September with an average of 0.15 mites per leaf. Phytoseiids *T. rhenanoides*, *E. quetzali*, and *E. stipulatus* were active beginning in July; *E. stipulatus* alone was collected and identified July through September (Fig. 95). Applaud Admire 2 and Lorsban were applied in May and June to manage grape leafhopper and obscure mealybug (Table 5).

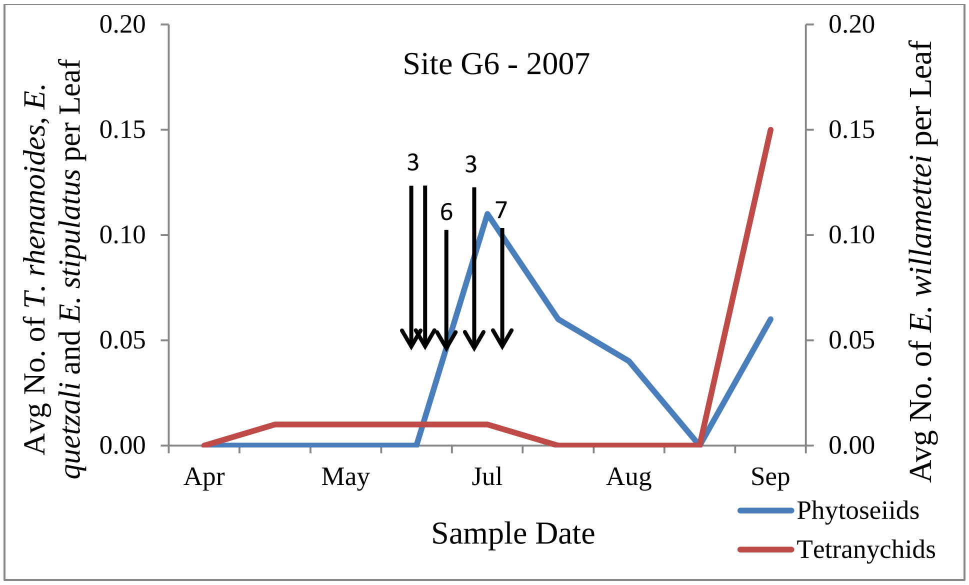

Figure 94. Average number of phytoseiids (*Typhlodromus rhenanoides*, *Euseius quetzali*, and *Euseius stipulatus*) and tetranychids (*Eotetranychus willamettei*) per leaf at G6, 2007 and the insecticides applied: 3 -Applaud, 6 - Admire 2, 7- Lorsban.

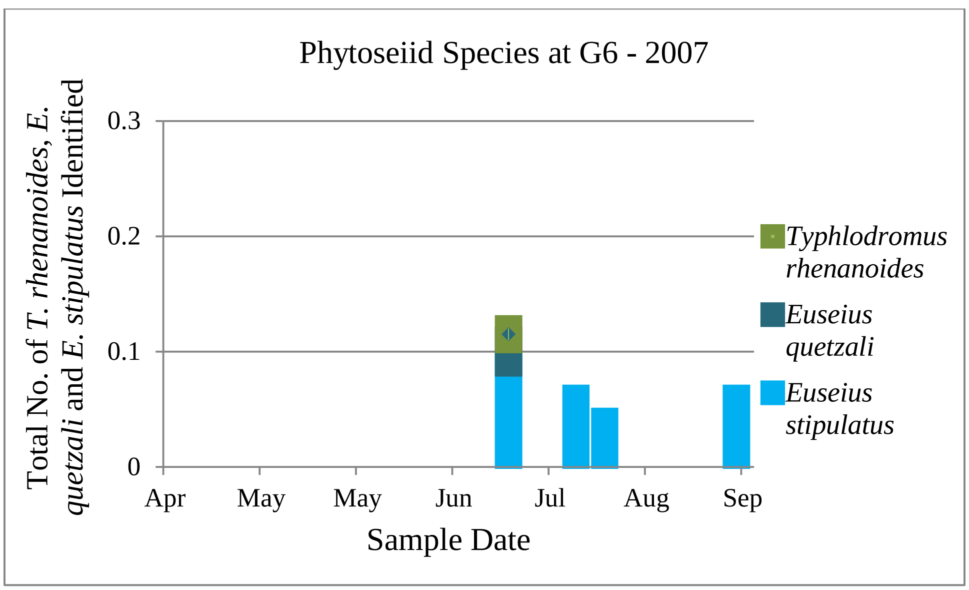

Figure 95. Total number of phytoseiids (*Typhlodromus rhenanoides*, *Euseius quetzali*, and *Euseius stipulatus*) slide mounted and identified at G6, 2007.

Some evidence of tetranychid control was demonstrated at vineyards G4 and G5, 2006 (Figs. 86 & 90). A combination of *Euseius* and *Metaseiulus* species present from July through October caused *T. urticae* and *E. willamettei* to decrease (Figs. 87& 91). The pesticide applications provided the majority of the control of *T. urticae* and *E. willamettei* at G2 and G7 (Figs. 82 & 94).

Distribution Pattern

All phytoseiid populations on grape showed a random distribution (Table 20). Type I and type IV phytoseiids made up the three most dominant species identified on grape in 2006 and types II, III and IV made up the three most dominant species in 2007.

Table 20. Statistical findings for grape, 2006 and 2007. The scale used to determine the CD: < 0.90 = regular; 0.90-1.10 = random; > 1.10 = aggregated.

				Poisson Regression			
Crop/Site	Year	Phytoseiids	Tetranychids	P-value		% of deviance	
Grape	2006			P	T	P	T
G1		N/A	0.78 Regular	0.0000	0.0000	100%	98.27%
G2		0.97 Random	0.88 Regular	0.0000	0.0000	99.98%	99.98%
G3		0.99 Random	N/A	0.0000	0.0000	99.99%	100%
G4		0.92 Random	0.99 Random	0.0000	0.0000	99.79%	99.99%
G5		0.93 Random	1.03 Random	0.0000	0.0000	99.87%	99.99%
G2	2007	0.98 Random	1.99 Aggregated	0.0000	0.0000	99.99%	99.99%
G4		0.95 Random	0.99 Random	0.0000	0.0000	99.91%	99.99%
G5		0.96 Random	0.82 Regular	0.0000	0.0000	99.96%	98.77%
G6		0.95 Random	0.99 Random	0.0000	0.0000	99.96%	99.93%

Strawberry

The average number of phytoseiids and tetranychids per leaf was 3.4 and 12.3 times greater, respectively, in 2006 than 2007. Phytoseiids averaged 0.08 individuals per leaf in 2006 and 0.27 in 2007 (Table 21). Tetranychids averaged 0.16 individuals per leaf in 2006 and 1.97 in 2007 (Table 21).

Table 21. Average number of phytoseiids and tetranychids counted on strawberry, 2006 and 2007.

Year	Field Site	Average Phytoseiid and Tetranychid Mites Counted per Leaf	
		Phytoseiidae	*Tetranychidae*
2006	S1	0.00	0.00
	S2a	0.01	0.05
	S2b	0.03	0.15
	S3	0.08	0.33
	S4	0.23	0.07
	S5	0.08	0.36
	S6	0.13	0.18
Season Avg.		0.08	0.16
2007	S2a	0.01	0.33
	S2b	0.61	4.62
	S4	0.68	4.67
	S6	0.05	0.15
	S7	0.01	0.10
Season Avg.		0.27	1.97

Neoseiulus californicus made up 93.9% of the phytoseiids identified in 2006 on strawberry, followed by *P. persimilis* with 6.1% of the season total. In 2007, *P. persimilis* made up 57% of the totals phytoseiids identified, followed by *N. californicus* (40.7%) and *E. stipulatus* (1.7%) (Table 22).*Tetranychus urticae* was the major tetranychid species present both seasons. *Tetranychus cinnabarinus* was also identified at site S6.

Table 22. Phytoseiids identified on strawberry, 2006 and 2007.

		Phytoseiidae		
Year	Field Site	*Euseius stipulatus*	*Neoseiulus californicus*	*Phytoseiulus persimilis*
Type		Type IV	Type II	Type 1
2006	S1	0	1	0
	S2a	0	6	0
	S2b	0	4	1
	S3	0	21	0
	S4	0	6	2
	S5	0	6	0
	S6	0	2	0
Total		0	46 (93.9%)	3 (6.1%)
2007	S2a	1	16	6
	S2b	1	23	13
	S4	0	130	213
	S6	5	12	13
	S7	0	4	0
Total		7 (1.7%)	169 (40.7%)	239 (57.6%)

Tetranychus urticae was found in July and August only at site S1-2006 at an average of 0.01 mites per leaf (Fig. 96). *Phytoseiulus persimilis* and *N. californicus* were located in July and August (Fig. 97) and peaked in July with an average of 0.08 mites per leaf (Fig. 96).

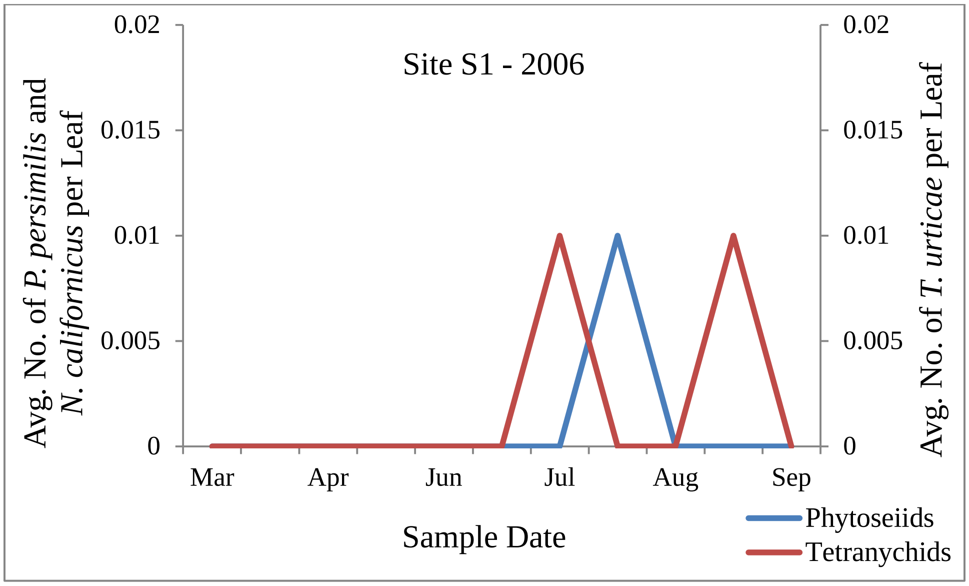

Figure 96. Average number of phytoseiids (*Phytoseiulus persimilis* and *Neoseiulus californicus*) and tetranychids (*Tetranychus urticae*) per leaf at S1, 2006.

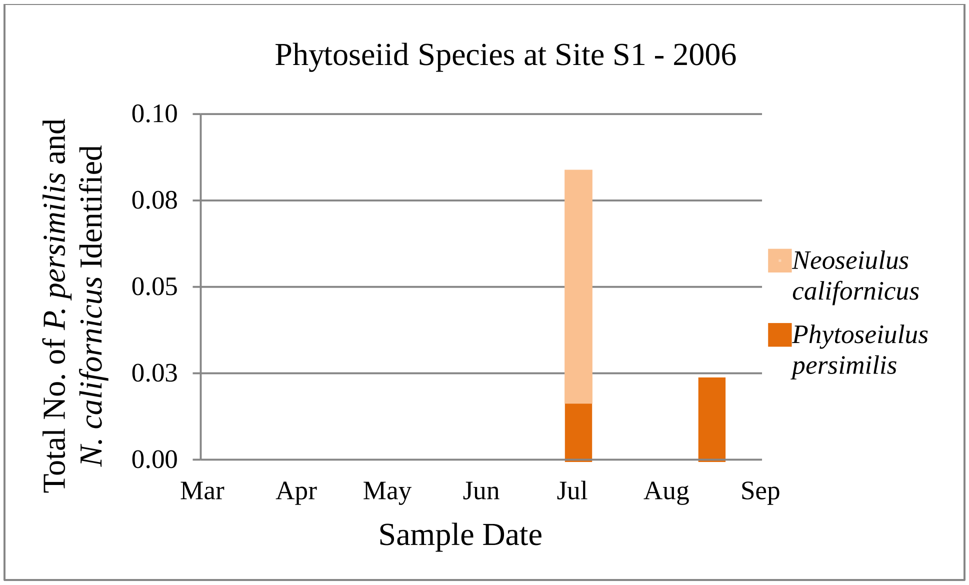

Figure 97. Total number of phytoseiids (*Phytoseiulus persimilis* and *Neoseiulus californicus*) slide mounted and identified at S1, 2006.

Tetranychus urticae was located in July only at S2a-2006 and peaked with an average of 0.26 mites per leaf (Fig. 98). *Phytoseiulus persimilis* and *N. californicus* were active in July and August and peaked in July (Fig. 99) with an average of 0.04 mites per leaf (Fig. 98). In 2007, *T. urticae* was active from April through September and peaked in May with an average of 1.29 mites per leaf (Fig. 100). *Phytoseiulus persimilis* and *N. californicus* were active from May through September (Fig. 101) and peaked in July with an average of 0.08 mites per leaf (Fig. 100).

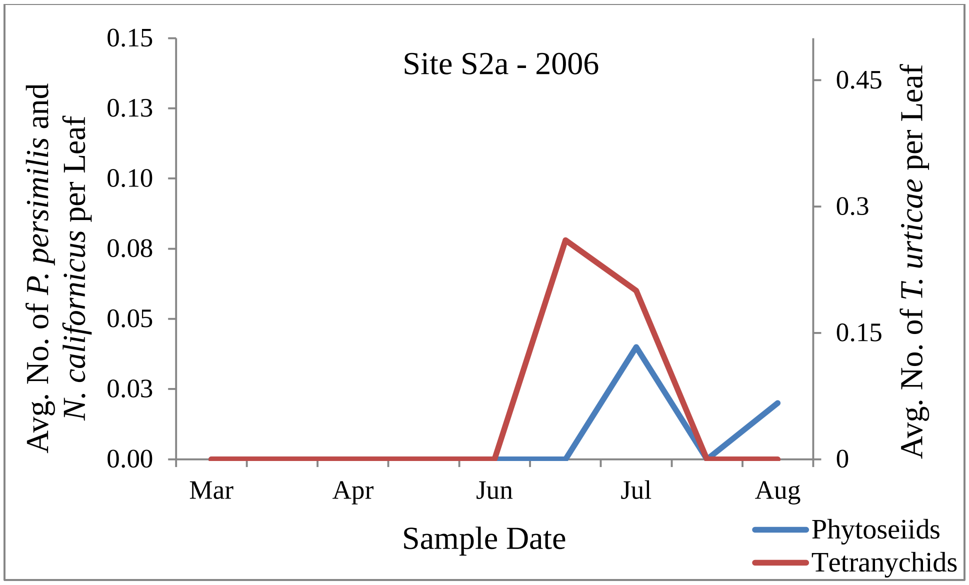

Figure 98. Average number of phytoseiids (*Phytoseiulus persimilis* and *Neoseiulus californicus*) and tetranychids (*Tetranychus urticae*) per leaf at S2a, 2006.

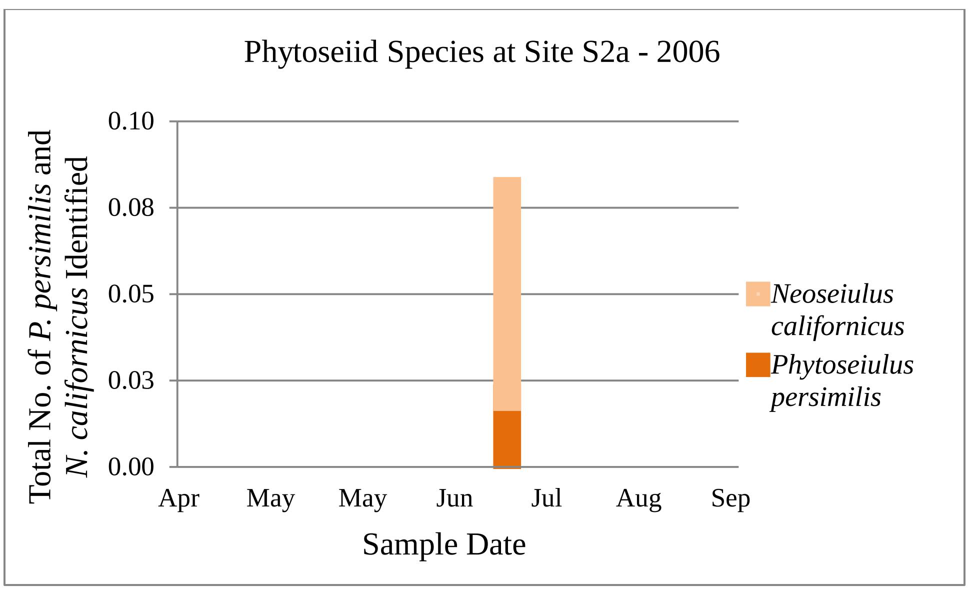

Figure 99. Total number of phytoseiids (*Phytoseiulus persimilis* and *Neoseiulus californicus*) slide mounted and identified at S2a, 2006.

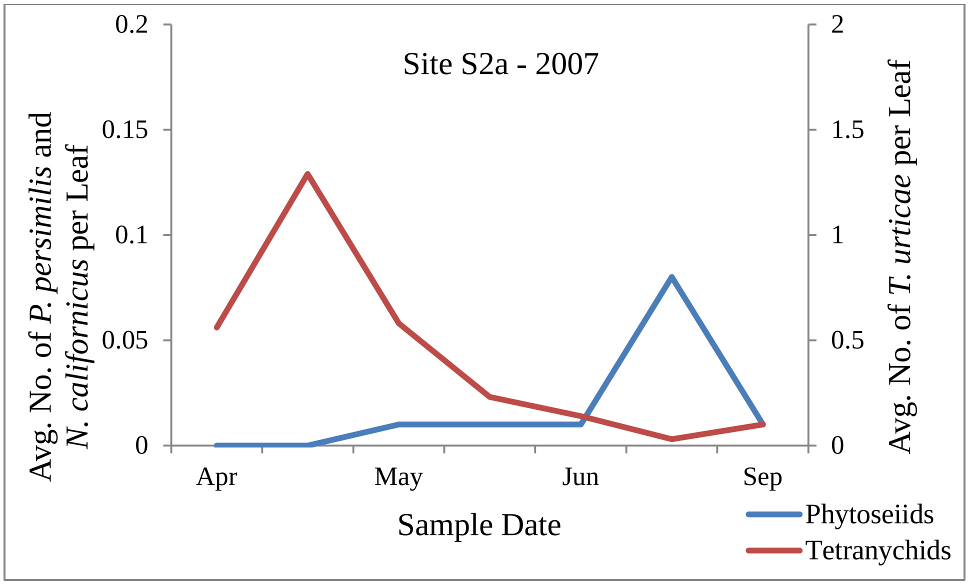

Figure 100. Average number of phytoseiids (*Phytoseiulus persimilis* and *Neoseiulus californicus*) and tetranychids (*Tetranychus urticae*) per leaf at S2a, 2007.

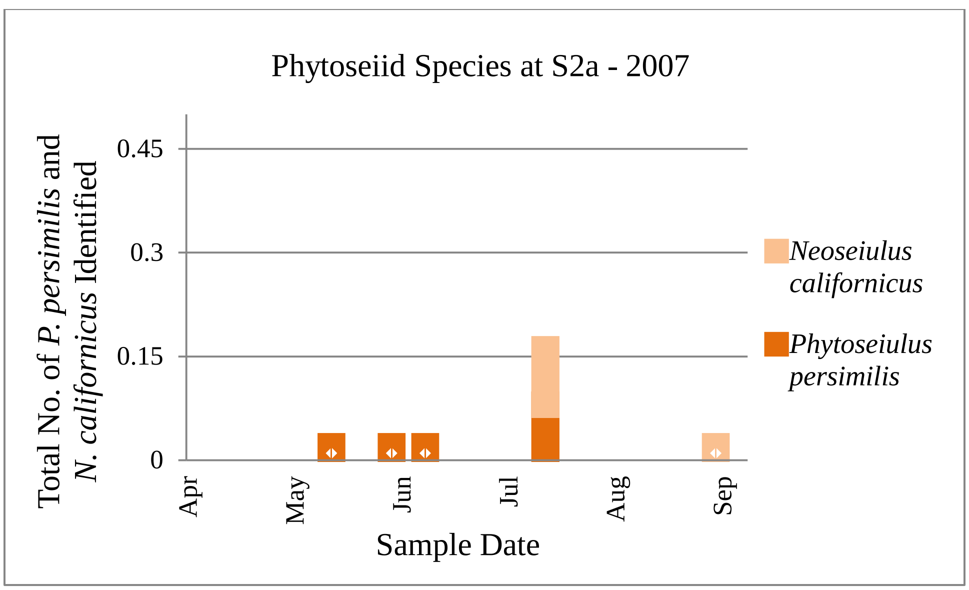

Figure 101. Total number of phytoseiid species (*Phytoseiulus persimilis* and *Neoseiulus californicus*) slide mounted and identified at S2a, 2007.

Tetranychus urticae was most active at S2b-2006 from May through September. The population peaked in June with an average of 0.62 mites per leaf, and then decreased through September (Fig. 102). *Phytoseiulus persimilis* and *N. californicus* appeared in July (Fig. 103) and remained active through September. The phytoseiid population peaked in July with an average of 0.12 mites per leaf (Fig. 102). Site S2b-2007 was available for sampling in September and October only. The population of *T. urticae* was severe with an average of 9.2 mites per leaf (Fig. 104). The population dropped by the following sample date to an average of 0.01 mites per leaf. The population of *Phytoseiulus persimilis*, *N. californicus* and *E. stipulatus* was also high in September (Fig. 105) with an average of 1.18 mites per leaf (Fig. 104). This population decreased greatly by the next sampling date to an average of 0.03 mites per leaf.

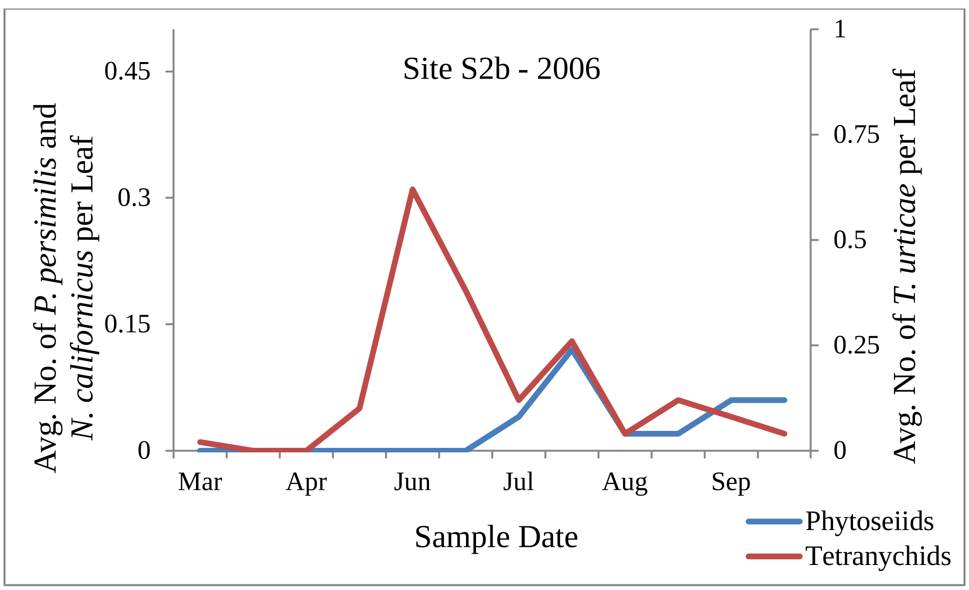

Figure 102. Average number of phytoseiids (*Phytoseiulus persimilis* and *Neoseiulus californicus*) and tetranychids (*Tetranychus urticae*) per leaf at S2b, 2006.

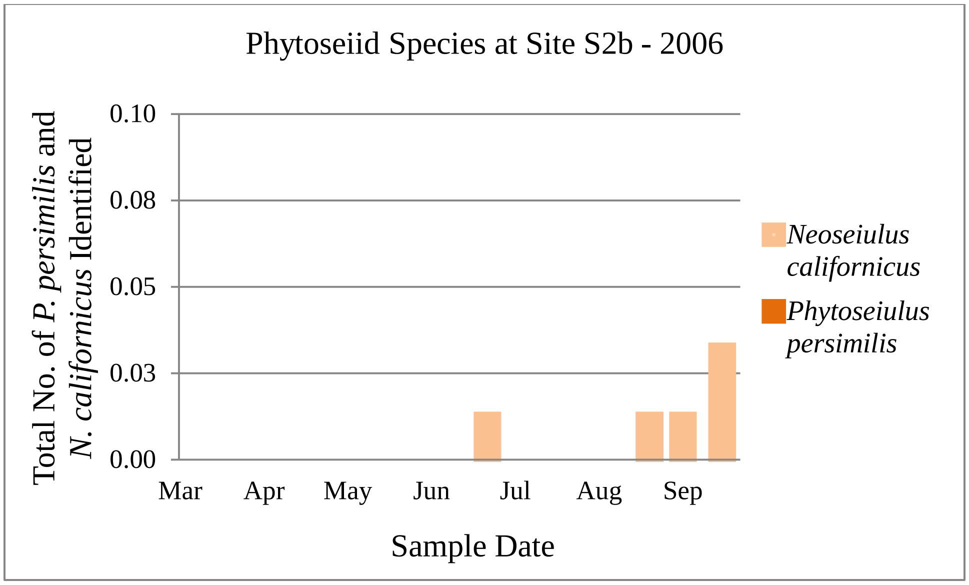

Figure 103. Total number of phytoseiids (*Phytoseiulus persimilis* and *Neoseiulus californicus*) slide mounted and identified at S2b, 2006.

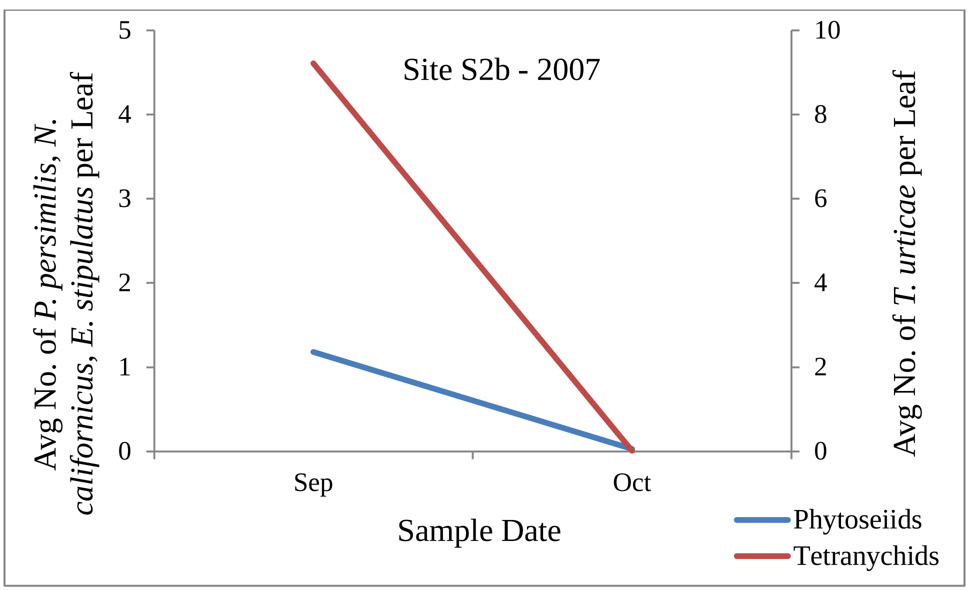

Figure 104. Average number of phytoseiids (*Phytoseiulus persimilis*, *Neoseiulus californicus*, *Euseius stipulatus*) and tetranychids (*Tetranychus urticae*) per leaf at S2b, 2007.

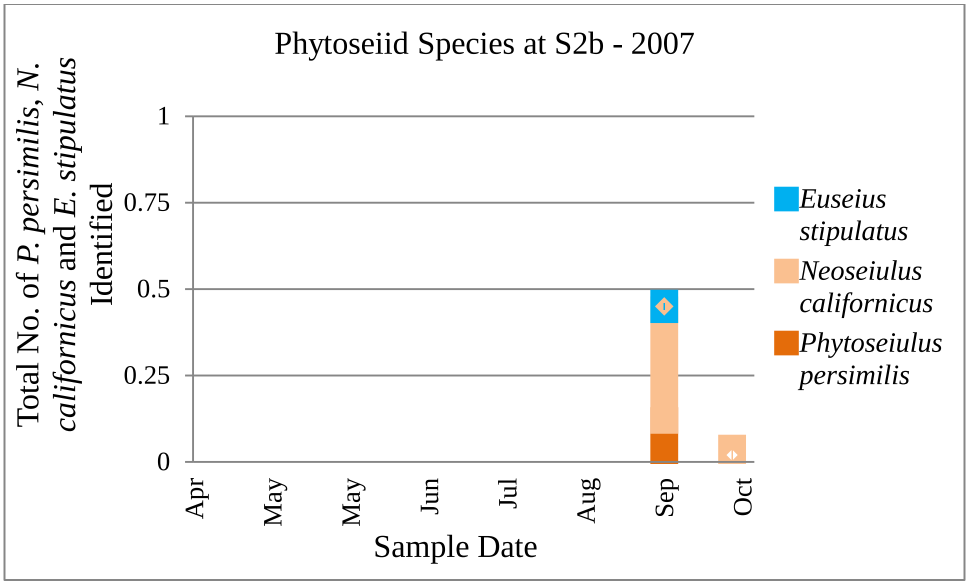

Figure 105. Total number of phytoseiids (*Phytoseiulus persimilis*, *Neoseiulus californicus*, and *Euseius stipulatus*) slide mounted and identified at S2b, 2007.

Tetranychus urticae was active from June through August at S3-2006. The population peaked in late June with an average of 2.4 mites per leaf (Fig. 106). *Neoseiulus californicus* was present from June through August (Fig. 107) and peaked in July with an average of 0.49 mites per leaf (Fig. 106).

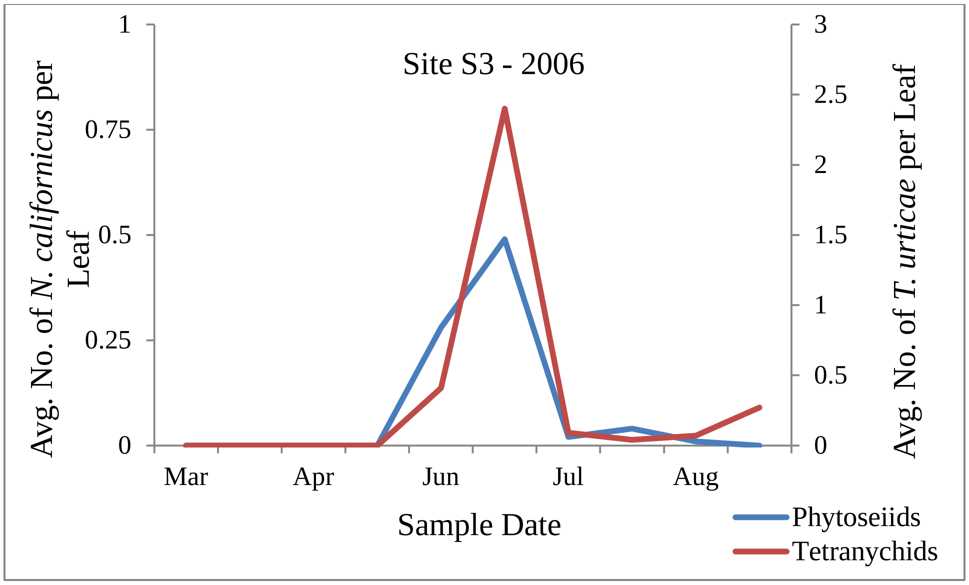

Figure 106. Average number of phytoseiids (*Neoseiulus californicus*) and tetranychids (*Tetranychus urticae*) per leaf at S3, 2006.

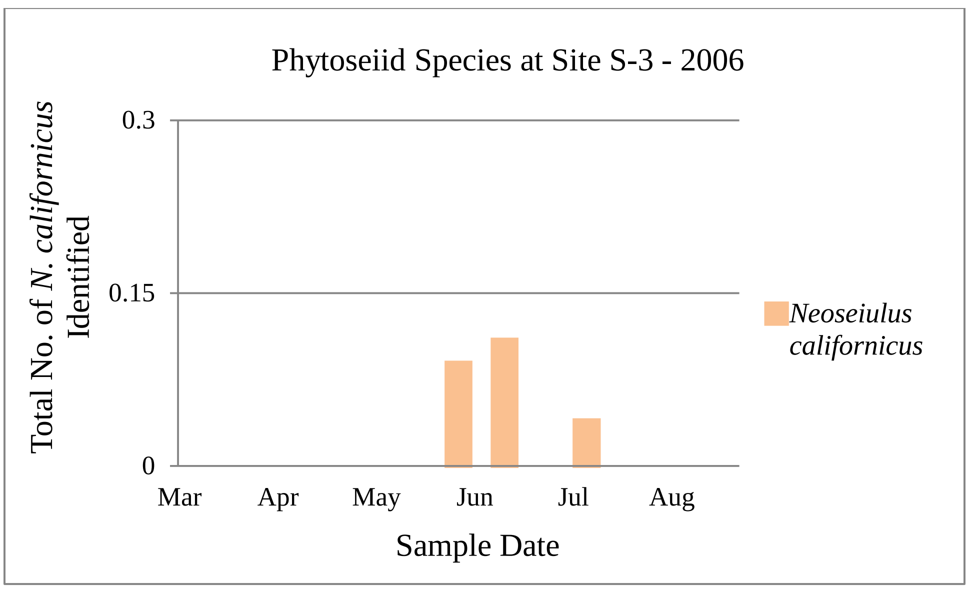

Figure 107. Total number of phytoseiids (*Neoseiulus californicus*) slide mounted and identified at S3, 2006.

Tetranychus urticae was located in June only at S4-2006 at an average of 0.2 mites per leaf (Fig. 108). *Phytoseiulus persimilis* and *N. californicus* were identified in June (Fig. 109) with an average of 0.7 mites per leaf (Fig. 108). In 2007, *T. urticae* was active from April through June and peaked in May with high average of 19.73 mites per leaf (Fig. 110). Phytoseiids *P. persimilis* and *N. californicus* were active May through June (Fig. 111) and peaked in early June with an average of 2.59 mites per leaf (Fig. 110).

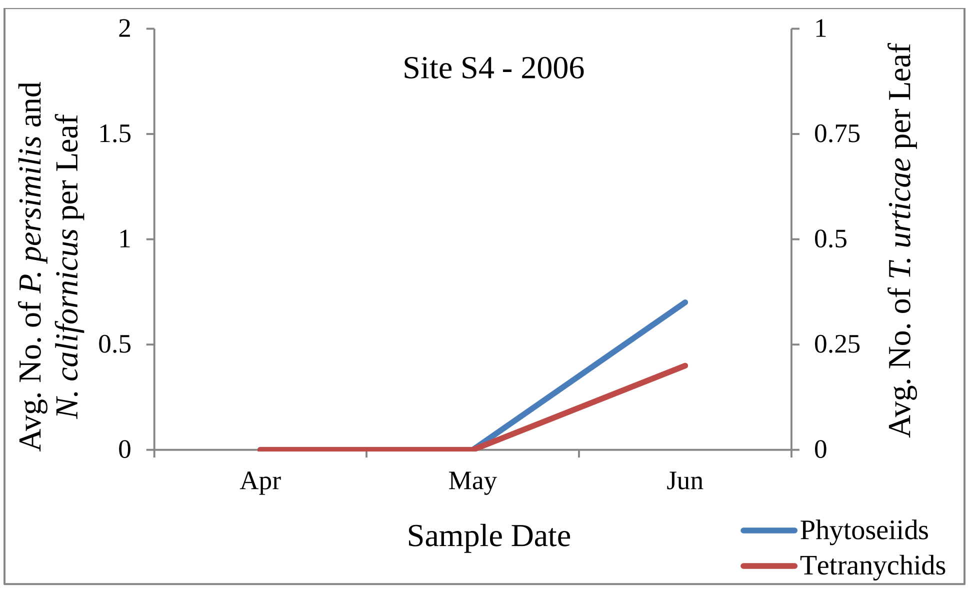

Figure 108. Average number of phytoseiids (*Phytoseiulus persimilis*, *Neoseiulus californicus*) and tetranychids (*Tetranychus urticae*) per leaf at S4, 2006.

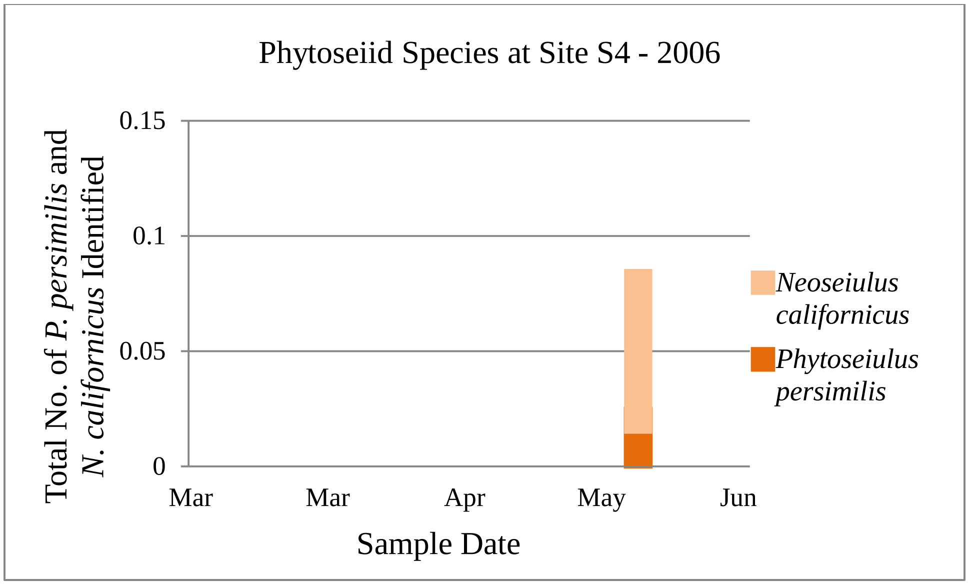

Figure 109. Total number of phytoseiids (*Phytoseiulus persimilis*, *Neoseiulus californicus*) slide mounted and identified at S4, 2006.

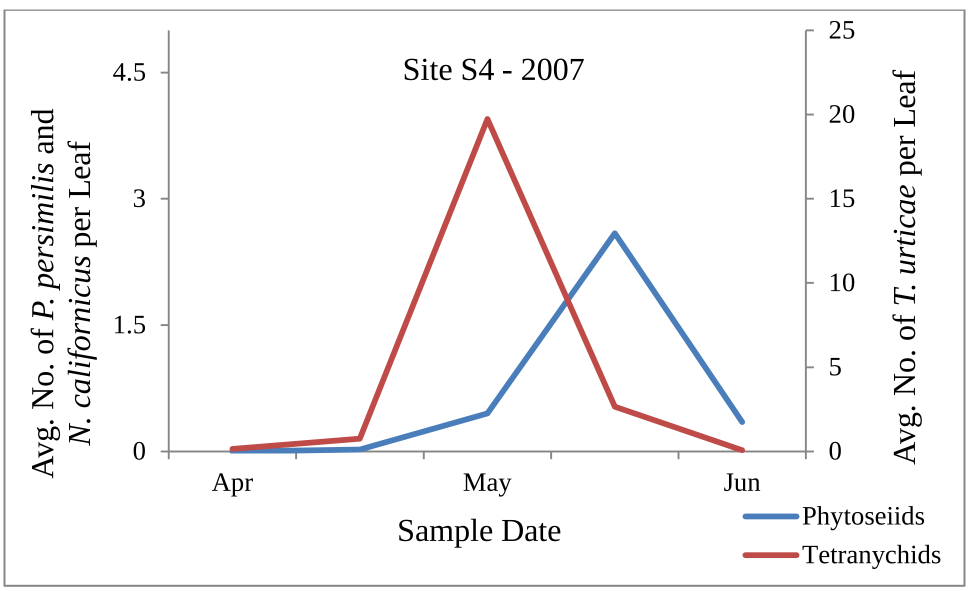

Figure 110. Average number of phytoseiids (*Neoseiulus californicus* and *Phytoseiulus persimilis*) and tetranychids (*Tetranychus urticae*) per leaf at S4, 2007.

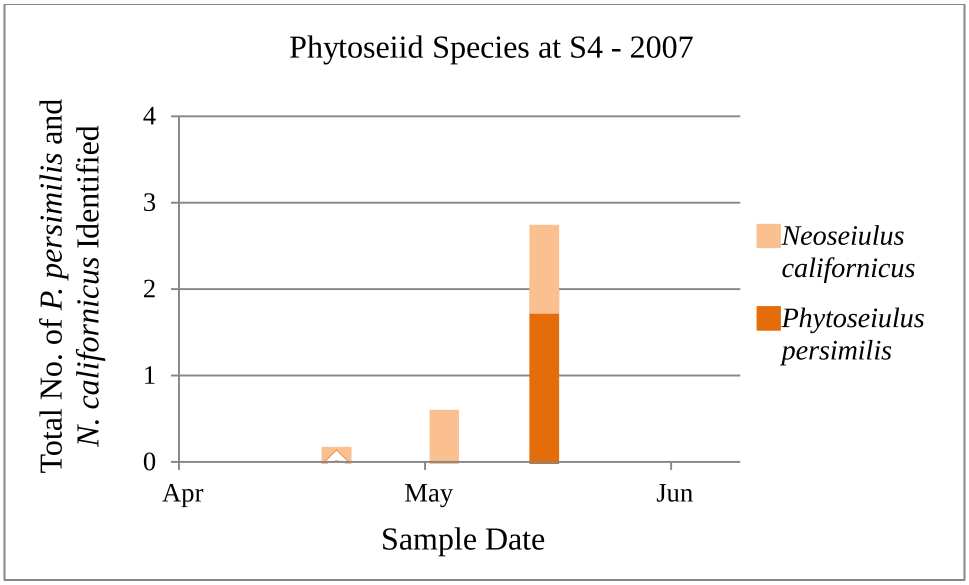

Figure 111. Total number of phytoseiids (*Phytoseiulus persimilis* and *Neoseiulus californicus*) slide mounted and identified at S4, 2007.

Tetranychus urticae was present at S5-2006 in March and June and the population peaked in June with an average of 1.1 mites per leaf (Fig. 112). *Neoseiulus californicus* was also present in March and June (Fig. 113) and peaked in June with an average of 0.28 mites per leaf (Fig. 112).

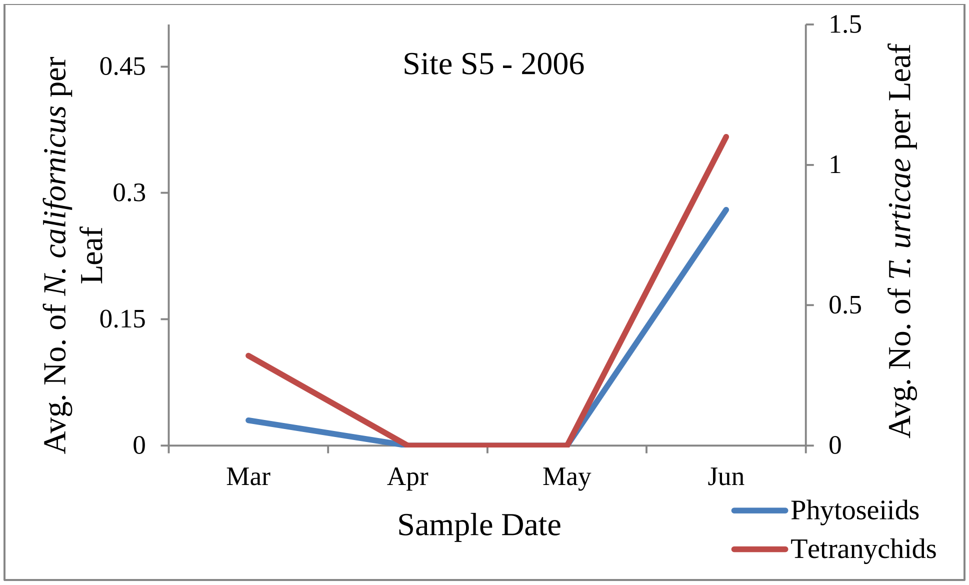

Figure 112. Average number of phytoseiids (*Neoseiulus californicus*) and tetranychids (*Tetranychus urticae*) per leaf at S5, 2006.

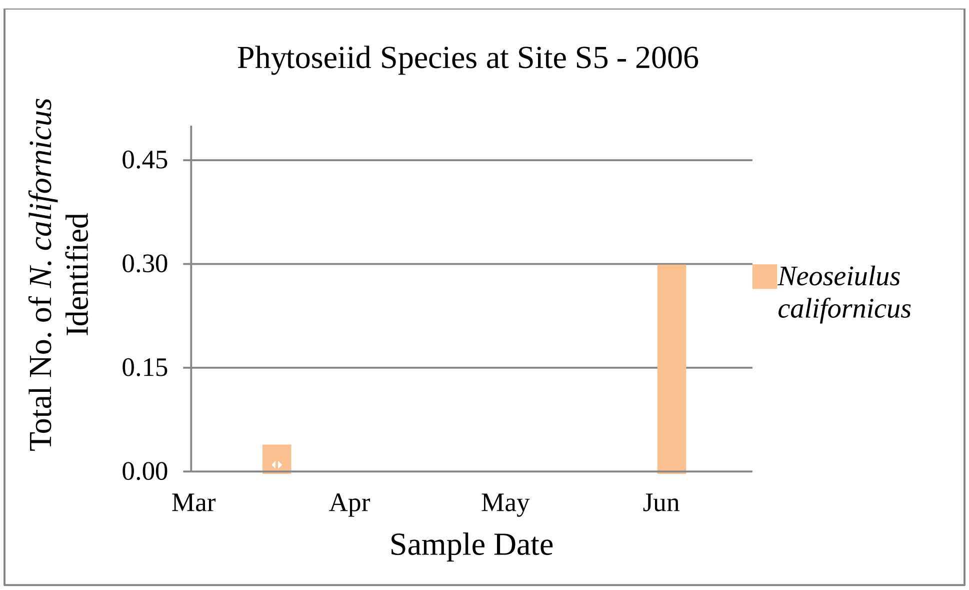

Figure 113. Total number of phytoseiids (*Neoseiulus californicus*) slide mounted and identified at S5, 2006.

Tetranychus urticae and *T. cinnabarinus* were active April through June at S6-2006. The population peaked in April with an average of 0.45 mites per leaf and declined gradually through June (Fig. 114). *Neoseiulus californicus* was active beginning in March, peaked in April (Fig. 115) with an average of 0.29 mites per leaf, and then decreased through June (Fig. 114).Many of the specimens were not suitable for identification and are not reflected on the species graph (Fig. 115). In 2007, *Tetranychus urticae* was active in May and June, and peaked in May with an average of 0.27 mites per leaf (Fig. 116). Phytoseiids *P. persimilis* and *N. californicus* were active in May and June. *Euseius stipulatus* was found in June (Fig. 117) when the phytoseiids population peaked with an average of 0.16 mites per leaf (Fig. 116).

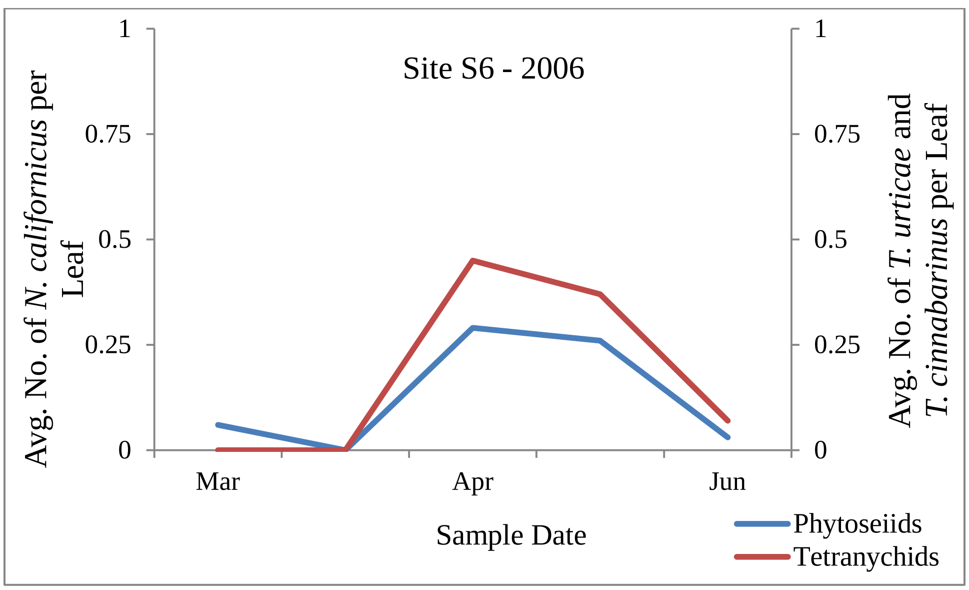

Figure 114. Average number of phytoseiids (*Neoseiulus californicus*) and tetranychids (*Tetranychus urticae* and *Tetranychus cinnabarinus*) per leaf at S6, 2006.

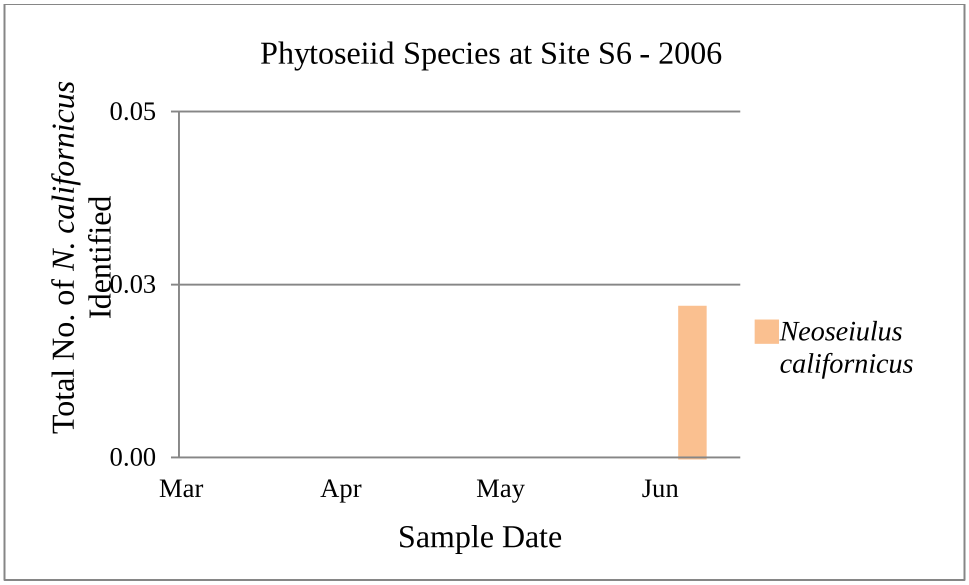

Figure 115. Total number of phytoseiids (*Neoseiulus californicus*) slide mounted and identified at S6, 2006.

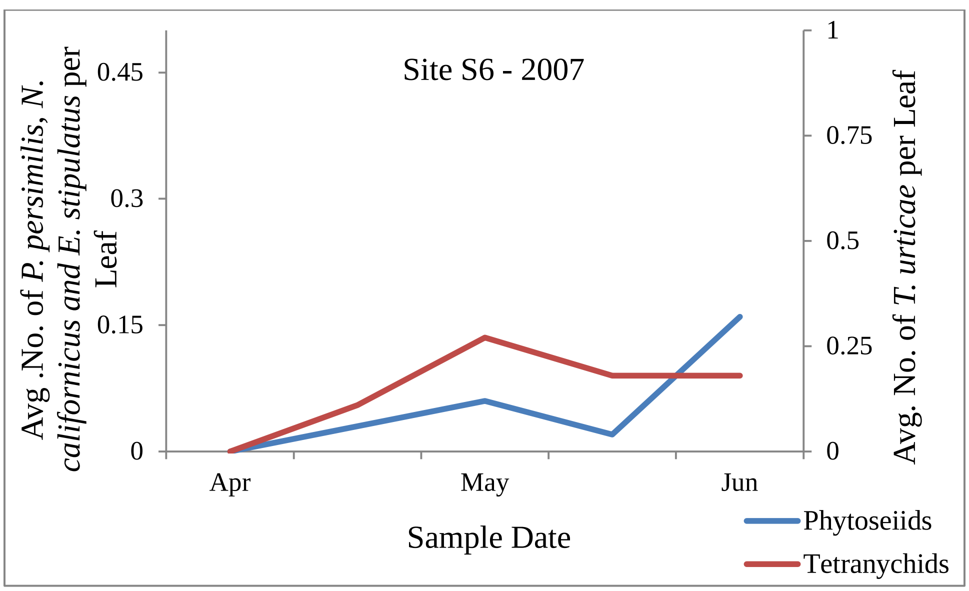

Figure 116. The average number of phytoseiids (*Phytoseiulus persimilis*, *Neoseiulus californicus*, *Euseius stipulatus)* and tetranychids (*Tetranychus urticae)* per leaf at S6, 2007.

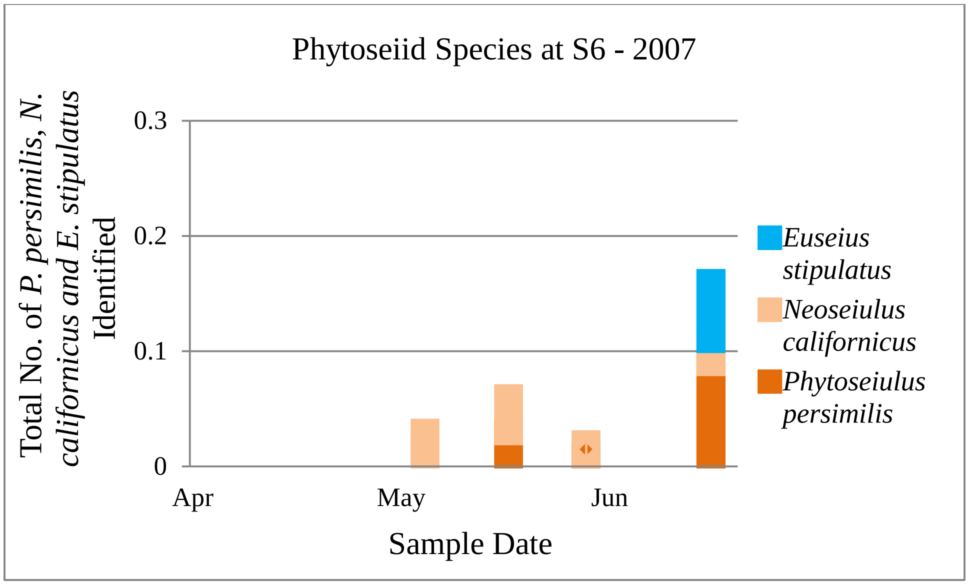

Figure 117. Total number of phytoseiids (*Phytoseiulus persimilis*, *Neoseiulus californicus*, and *Euseius stipulatus)* slide mounted and identified at S6, 2007.

Tetranychus urticae was active at S7-2007in July, August and September, and peaked in September with an average of 0.16 mites per leaf (Fig. 118). *Neoseiulus californicus* was active in August and September (Fig. 119), and peaked in September with an average of 0.03 mites per leaf (Fig. 118).

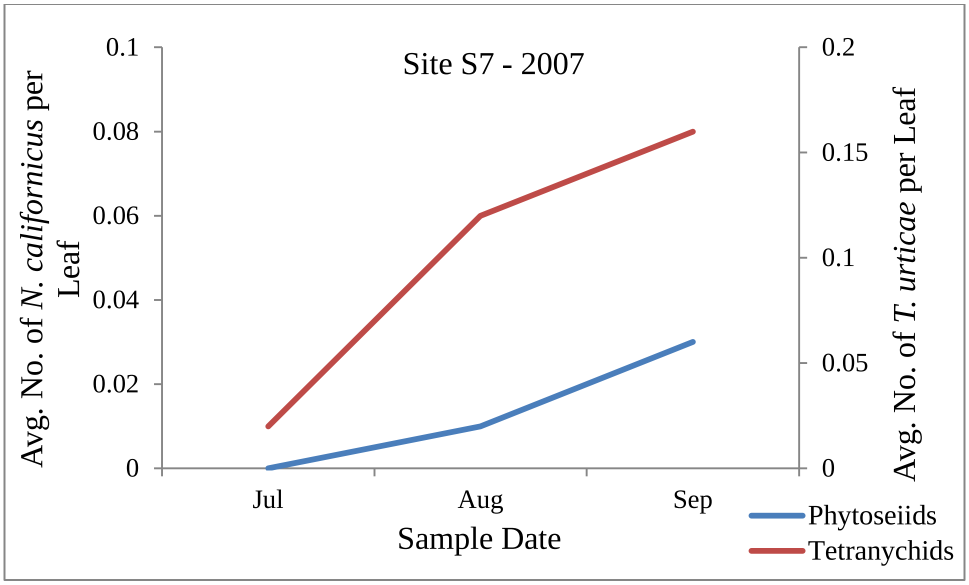

Figure 118. Average number of phytoseiids (*Neoseiulus californicus)* and tetranychids (*Tetranychus urticae*) per leaf at S7, 2007.

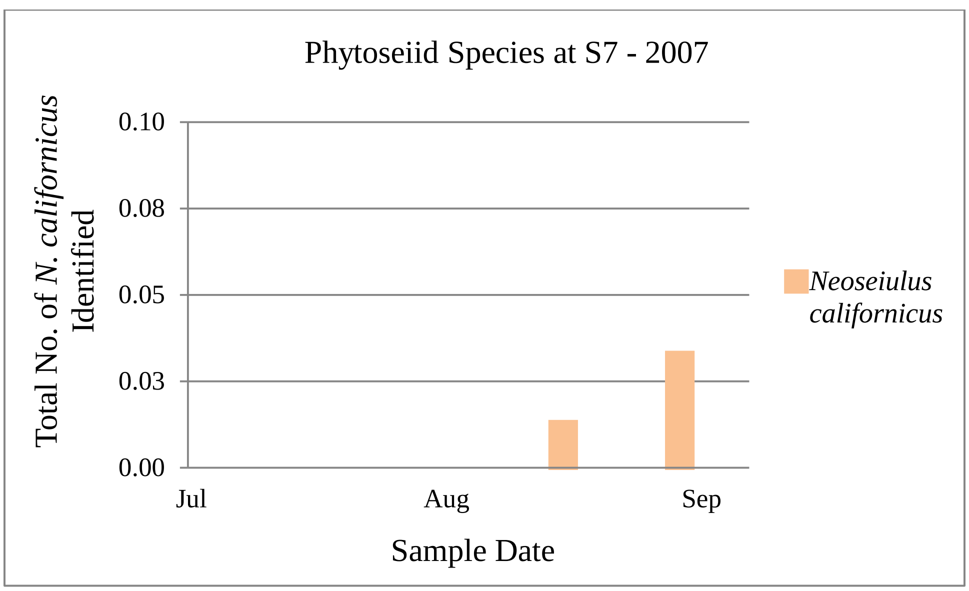

Fig. 119. Total number of phytoseiids (*Neoseiulus californicus*) slide mounted and identified at S7, 2007.

A measurable phytoseiid population was recorded in 10 of the 12 data collected in strawberry in 2006 and 2007. Of those 10, 7 demonstrated a pest-predator relationship with the phytoseiids responding to and causing a decline in the pest mite population. The three sites that did not demonstrate a pest-predator relationship included S2b-2006, S2a-2007 and S4-2006. At sites S2b-2006 and S2a-2007, *T. urticae* was active before the phytoseiids population developed and the phytoseiid were not able to manage the tetranychid population early in the season (Figs. 102 and 100).

Distribution Pattern

All but one phytoseiid population in 2007 had a random distribution pattern. The majority of tetranychid populations also showed a random population; three populations in 2007 were aggregated (Table 23).

Table 23. Statistical findings for strawberry, 2006 and 2007. The scale used to determine the CD: < 0.90 = regular; 0.90-1.10 = random; > 1.10 = aggregated.

				Poisson Regression			
Crop/site	Year	Phytoseiids	Tetranychids	P-value		% of deviance	
Strawberry	2006			P	T	P	T
S1		0.99 Random	0.99 Random	0.0000	0.0000	100.0%	99.99%
S2a		0.99 Random	0.97 Random	0.0000	0.0000	99.99%	99.98%
S2b		0.97 Random	0.93 Random	0.0000	0.0000	99.97%	99.87%
S3		0.95 Random	1.05 Random	0.0000	0.0000	99.94%	99.98%
S4		0.87 Regular	0.98 Random	0.0000	0.0000	99.44%	99.99%
S5		0.95 Random	0.86 Regular	0.0000	0.0000	99.38%	99.91%
S6		0.90 Random	0.91 Random	0.0000	0.0000	99.69%	99.75%
S2a	2007	0.98 Random	1.32 Aggregated	0.0000	0.0000	99.99%	99.76%
S2b		0.80 Regular	2.85 Aggregated	0.0000	0.0000	98.53%	94.66%
S4		0.99 Random	3.86 Aggregated	0.0000	0.0000	99.55%	96.35%
S6		0.94 Random	0.98 Random	0.0000	0.0000	99.88%	99.95%
S7		0.99 Random	0.95 Random	0.0000	0.0000	99.99%	99.91%

CHAPTER V

DISCUSSION

Avocado

Oligonychus perseae and *E. hibisci* were expected to be the principal pest and predator mites identified on avocado. *Oligonychus perseae* is recognized as the most important foliage feeding mite the coastal regions of San Luis Obispo, Santa Barbara and Ventura counties (Hoddle, n. d.) and was the only tetranychid mite located during this survey. *Eotetranychus* spp. have been noted on occasion along foggy coastlines of Santa Barbara and San Luis Obispo counties (Avocado Pest Management Guidelines, 2014), but was not found during this survey. *Euseius hibisci* is the most common phytoseiid predator in California avocados orchards (McMurtry and Johnson, 1965; McMurtry et al., 1984; Hoddle, 1998; Takano-Lee & Hoddle, 2002) and *G. annectans* has been reported in coastal orchards, but only rarely (Hoddle, n. d.). However, contrary to the current literature, *E. stipulatus* was the most common phytoseiid identified during this survey. This type IV species was introduced to citrus in southern California in 1971 to manage citrus red mite (McMurtry, 1977; McMurtry et al., 1984) and was not known to occur in San Luis Obispo County (McMurtry, personal communication, July 10, 2007). There were minor occurrences of *T. eharai* and *A. similoides* at A1, 2006 and *E. quetzali* at site A2, 2006. *Typhlodromina eharai* feeds and reproduces only on tydeiid mites on avocado in California (Muma and Denmark, 1969; McMurtry & Congdon, 1986; McMurtry et al., 2013) and tydeiids were plentiful during the spring bloom at site A1. *Amblyseius* *similoides* has been collected from coastal areas on citrus and avocado. However, this predator is not considered to be closely associated with tetranychid pests common to citrus or avocado (McMurtry & Congdon, 1986). *Euseius quetzali* has been recorded on native *Quercus, Rubus,* and *Prunus* trees (McMurtry & Congdon, 1986). Site A1 is located between a citrus planting and an open pasture (Fig. 2) and site A2 has native vegetation to the east and west of the sampled orchard (Fig. 3). It's likely that these species moved in from neighboring vegetation. Additional species were not found at site A3. This site has approximately 6 small citrus trees and is located across from an open field. Neither provided a significant habitat for phytoseiids to develop a diverse species complex.

Oligonychus perseae were active during late summer or fall following applications of Agri-Mek or Epi-Mek and Omni Oil (Figs. 33, 41, and 35), summer through fall (Fig. 37) and spring and fall in the absence of insecticide applications (Fig. 43). Heavy bloom and the presence of pollen on the leaves was recorded at in April A1-2007. Tydeiids were found on 45 of the 100 leaves sampled on this date and *E. stipulatus* were observed feeding on pollen that had fallen onto these leaves. Tydeiids were present mostly in the spring and fall at each of the three orchards (Figs. 33, 35, 39, 41and 43). Phytoseiids appeared at different times during the avocado season. At A1-2006, phytoseiids appeared late in the season, August through September. The following year at the same site, the height of the *E. stipulatus* population was found in April. *Euseius* predators were was active in June and July and late October at A2-2006 and in August and October in 2007. *Euseius stipulatus* were active in June at A3-2006 and steadily increased though October, but was found in September only in 2007. The lack of a defined trend is likely due to the effects of pesticide and the availability of prey.

Phytoseiids likely provided some regulation of *O. perseae* at all sites. However, the presence of these phytoseiids did not consistently result in fewer *O. perseae*. For example, at A2-2006, the phytoseiids appeared with the season's peak population in June (Fig. 37). *Oligonychus perseae* also appeared in June, but remained active throughout August. *Euseius stipulatus* and *E. quetzali* did not cause the population of *O. perseae* to decline. Pesticides applied at June and July (Figs. 79 & 81) suppressed *O. perseae* populations; therefore, phytoseiids alone did not control *O. perseae*. Economic thresholds have not been established, and for this reason, this work cannot confirm if *O. perseae* was maintained below an economic threshold. *Euseius* spp. experience a higher rate of reproduction on a pollen diet and *O. perseae* may have served as a secondary food source. The limited regulation by these predators is likely due to the generalized feeding habits as evidenced by the random distribution pattern of the type III and type IV phytoseiids identified on avocado.

Cherimoya

No reports of mite pests or predators on cherimoya were found in the literature. Information regarding general pests in California noted Argentine ants, *Iridomyrmex humilis*, and long-tailed mealybug, *Pseudococcus adonidum*, as the most notable pests in orchards (Phillips et al., 1987). *Eotetranychus* spp. were found at all three orchards and were the only tetranychid pest mites located (Table 10). *Euseius stipulatus* was the most abundant phytoseiid identified both seasons at each cherimoya orchard (Table 11). Other species identified included *E. quetzali* at CH3, *A. limonicus* at CH1, and *G. occidentalis* CH1 and CH3, and *A. similoides* at all three sites. Site CH1 is in close proximity to small citrus plantings (Fig. 5), CH2 is near a large avocado planting (Fig. 6), and CH3 is near native vegetation and a small planting of assorted citrus (Fig. 7). It's possible that the lesser phytoseiid species moved in from neighboring plantings.

Eotetranychus spp. first appeared in March or May in 2006, and in April, 2007. The population decreased during late summer and rebounded again in September to October. Phytoseiids appeared in May in 2006 and in April in 2007 and also decreased in July or August at each orchard both seasons. A late season increase was seen only at CH1 and CH3, 2006. The trees at CH2 and CH3, 2006 were pruned in May (Figs.49 & 53); the young trees at CH1 were only thinned (Fig. 45). The pruning and thinning caused the population of phytoseiids and *Eotetranychus* spp. to decline, but both populations rebound in June. In 2007, trees were topped in April at CH3 only. The same trend of an immediate population decrease was observed, followed by a rebound during the following weeks. The population trends recorded for phytoseiids and *Eotetranychus* spp. were comparable. Both appeared in the spring and decline after the pruning events and during mid to late summer. *Eotetranychus* spp. was more successful in rebounding in the fall than were the phytoseiids.

When phytoseiids appeared, *Eotetranychus* spp. declined, providing some evidence of regulation. For example, at CH1 and CH3, 2006, phytoseiids appeared two weeks after *Eotetranychus* spp. which then declined. Whereas at CH1 and CH2, 2007, the phytoseiid population failed to develop beyond 0.12 and 0.08 mites per leaf, respectively, and the *Eotetranychus* spp. population remained steady through October. Pesticides were not applied at any of the three orchards, and therefore, did not play a role in managing *Eotetranychus* spp. Economic thresholds have not been established for cherimoya. The level of management provided by phytoseiids appears to negate the need for pesticides. The patterns of occurrence found here reflect the natural behavior of *Eotetranychus* spp. on cherimoya. A greater ability of *E. stipulatus* to regulate pest mites would be expected here than what was found with *O. perseae* on avocado. The reason being, *Eotetranychus* spp. do not spin the same type of dense circular webbing as O. *perseae* (Avocado Pest Management Guidelines, 2014). The random distribution pattern of the type II, type III and type IV phytoseiids identified supports their limited ability to consistently regulate *Eotetranychus* spp. which have an aggregated distribution pattern. The population trends suggest a pattern of regulation, but the phytoseiids' feeding behavior results in a random distribution, one contributing factor that prevents them from providing greater regulation of *Eotetranychus* spp.

Caneberry

Tetranychus urticae was the principal pest mite identified on caneberry and is recognized as the major tetranychid pest on caneberry (Caneberry Pest Management Guidelines, 2010). The *Eotetranychus* species thought to be *E. sexmaculatus* were observed in the field, but not positively identified to species. This species is visually similar to *E. lewisi* which is recognized as an emerging pest on caneberry and moving from raspberry plantings into strawberry fields in Ventura County (Caneberry Pest

Management Guidelines, 2010). *Phytoseiulus persimilis* was expected to be the principal phytoseiid due to the augmentative releases conducted at each caneberry sites sampled as confirmed by ranch managers and on site Pest Control Advisors. However, details about the releases were only available from C1-2006, C3-2007, and C4-2007. *Phytoseiulus persimilis* is recognized as the most reliable predatory mite used for biological control (Caneberry Pest Management Guidelines, 2010), but it made up only 7% of the phytoseiids identified in 2006 (Table 14). *Amblydromalus limonicus* and *E. stipulatus* made up 45% and 34%, respectively, of phytoseiids identified in 2006. *Phytoseiulus persimilis* made up 40% and *A. limonicus* made up 21% of the phytoseiid identified in 2007. Minimal findings of *P. persimilis* can be attributed to errors in release methods (Campbell & Lilley, 1999), inability to efficiently locate their preferred host or extreme temperature fluctuations (Skirvin & Fenlon, 2003). Additionally, lab-reared specimen can be subjected to contamination in the lab or cannibalism during transport (Walzer & Schausberger, 1999; Schausberger & Croft, 2000), both of which would have adverse effects on their quality and quantity upon release.

Tetranychus urticae and *Eotetranychus* spp. mostly appeared in April or May and experienced a drop in the population in July or August. When the population declined in July, the population resurged in August (Figs. 56 & 65). When the population declined in August, there was a minor increase in late June (Figs. 66 & 70) or none at all (Figs. 74, 58, 60 & 62). Phytoseiids appeared in April or May, peaked in June or July and declined through August and September. Phytoseiids and tetranychids were active at similar times during the season.

Evidence of regulation by phytoseiids was apparent at most caneberry locations. *Phytoseiulus persimilis* and *N. californicus* provided some control of *T. urticae* and *Eotetranychus* spp. at C1a and C1b-2006 (Fig. 56 &74), C2-2006 (Fig. 60), C3-2006 and C5-2007 (Figs. 62 &72). Augmentative releases of *P. persimilis* were conducted all caneberry sites except for C1-2007, but information was only available for C1-2006, C3-2007, C4-2007 and tetranychid management was evident at each. For example, at C1b-2006, *P. persimilis* were released in June and August and the population of *T. urticae* and *Eotetranychus* spp. remained at or below an average of 0.06 mites per leaf through September (Fig. 74). Damage thresholds have not been developed for caneberry, but a pest/predator ratio of 1 to 10 is recommended for effective biological control (Caneberry Pest Management Guidelines, 2014). In 2006, C1a and C3 closely matched the pest/predator recommended ratio in July with ratios of 1/10.4 and 1/12.5, respectively (Figs. 56 & 62). In April at C5-2007, a pest predator ratio of 1/9 was recorded (Fig 72) and in June at C1a-2007, the pest predator ratio of 1/11 was recorded (Fig. 58); however, the tetranychid population increased 5 fold the following sample date and the phytoseiid population did not increase. *Metaseiulus johnsoni* may have contributed to managing the pest mites at C4-2007 (Fig. 68) as it was generally located among the pest populations. Site C1 is a pesticide free operation and provided a study of the resident phytoseiids behavior in the absence of pesticides.

Grape

The tetranychid species site identified was presumed to be *E. willamettei* which are common in coastal vineyards (Costello, 2007; Daane et al., 2005; Hanna et al., 1997; Grape Pest Management Guidelines, 2014). *Eotetranychus willamettei* prefers cooler temperatures and considered a pest in the north coast grape growing regions of California, in the Salinas Valley and the Sierra Foothills (Grape Pest Management Guidelines, 2014). *Euseius* species were the primary phytoseiids identified on grape in 2006 and 2007. Published reports name *G. occidentalis* as the most important biological control agent that preys on Pacific spider mites found in vineyards of California's Central Valley and North Coast (Costello, 2007; Kinn & Doutt, 1972b; Grape Pest Management Guidelines, 2014). However, in the absence of pacific spider mites, this survey of the central coast produced only one *G. occidentalis* in 2006 and 8 in 2007 (Table 19).

Tetranychus urticae and *E. willamettei* appeared April, May, June or July at the vineyards sampled. Population peaks also varied between June, July August and September. Phytoseiids mostly appeared in June and July and populations peaked in late July, August and September. The absence of a definite trend for tetranychids is likely due to the effects of pesticide applications. Phytoseiids were able to rebound after the pesticide applications (Figs. 79, 81 & 93). Tetranychids rebounded at G2-2006 and G7-2007 after the pesticide applications (Figs. 79 & 93).

Pesticide applications at the larger commercial vineyards, G2 and G6 (Figs. 81 & 93), likely provided the majority of control of *T. urticae* and *E. willamettei*. A greater population of phytoseiids was recorded at both vineyards after the summer pesticide applications when pest mites were below an average of 1.0 mite per leaf. The remainder of the vineyards received applications of sulfur only. Sites G4 and G5 had a greater variety of *Euseius* and *Metaseiulus* species present each year than those sprayed with pesticides (Table 19) and G4-2006 showed evidence of late season control (Fig. 85). The phytoseiid population peaked in July and remained active through October, while the *T. urticae* and *E. willamettei* remained at or below an average of 0.06 mites per leaf. Damage thresholds have been developed for *T. pacificus*, a major pest on grape in the San Joaquin Valley, but not for *E. willamettei* (Grape Pest Management Guidelines, 2014). Therefore, it's unclear if phytoseiids would be able to maintain *E. willamettei* at a level necessary to minimize damage in a vineyard.

Strawberry

Tetranychus urticae is the major tetranychid pest mite on strawberry in California and *T. cinnabarinus* and *E. lewisi* are named as minor pests (Strawberry Pest Management Guidelines, 2014). *Tetranychus urticae* was the dominant pest mite both seasons and *T. cinnabarinus* was located at S6-2006 only. *Phytoseiulus persimilis* was expected to be the dominant phytoseiid on strawberry due to augmentative releases conducted at each field surveyed. *Phytoseiulus persimilis* and *N. californicus* are recognized as naturally occurring predators established in most coastal strawberry fields. These predators and *N. fallacis* are commercially available and are released to control spider mites; *P. persimilis* is most frequently used (Strawberry Pest Management Guidelines, 2014). *Neoseiulus californicus* was the dominant phytoseiid identified in 2006 (Table 23). The balance shifted in 2007 with 169 *N. californicus* and 239 *P.*

persimilis. *Euseius stipulatus* was collected only at two sites in 2007 and it's possible that the type IV phytoseiid moved in from neighboring vegetation as was discussed with *E. quetzali*, *A. similoides* and *T. eharai* on avocado and cherimoya.

Tetranychus urticae appeared April, May, June or July and did not sustain steady populations beyond one month. Populations that appeared prior to May had declined by June (Figs. 107, 109, 111, 113 & 115). Populations that appeared in June had decreased by July (Figs. 97 & 105). Populations that appeared in July were present but in low numbers into August (Figs. 95 & 117). Phytoseiids showed a similar trend at 9 of the 11 data sets, the exceptions being S2b-2006 and S2a-2007 (Figs.101 & 99). The similar population trend is supported by the feeding behaviors of type I *P. persimilis* and type II *N. californicus* and their ability to reproduce successfully on *T. urticae*.

Phytoseiulus persimilis and *N. californicus* both responded to *T. urticae* and caused that population to decline. Site S3-2006 had an abundant population of *N. californicus* in June and July and matched the peak and decline of *T. urticae* (Fig. 105). The tetranychid population peaked at an average of 2.5 mites per leaf in June and decreased to near zero by August (Fig. 103). The economic threshold for strawberry is 5 mites per leaflet for early season planting and 10 mites per leaflet for summer plantings (Strawberry Pest Management Guidelines, 2014). *Neoseiulus californicus* was not released and no other phytoseiids, including *P. persimilis*, were recovered. Therefore, it is presumed that the naturally occurring population of *N. californicus* maintained the population of *T. urticae* below the economic threshold.

Phytoseiid Diversity By Crop

Phytoseiid diversity varied with each crop surveyed. Strawberry was the least diverse system with three genera and three species identified (Table 24). Avocado followed with three genera and four species; Cherimoya had four genera and 5 species; Caneberry, combining raspberry and blackberry, had 7 genera and 7 species. Grape showed the greatest diversity with 7 genera and 12 different species identified. The fewest species were collected from two very different cropping systems. Strawberry is a highly managed annual crop that is host to a variety of insect pests and is susceptible to diseases such as powdery mildew. Avocado and cherimoya are permanent tree crops that are associated with a narrow range of pests and pesticides.

The significance of each species identified also varied. Table 25 shows species that were collected on a minimum of 5 different sample dates, the one exception being blackberry. Blackberry was sampled from only one location; therefore, species that were collected at least twice within one season were included on this table. The strawberry cropping system supported the greatest number of type I and type II phytoseiids, whereas only type IV phytoseiids were collected from avocado and cherimoya. Raspberry had a mixture of type 1, type II, type III and type IV phytoseiids while blackberry had only type II and type III phytoseiids. Grape, which had the greatest diversity of phytoseiids, had only 6 type I phytoseiids, the rest of which were type IVs.

Table 24. Species diversity identified in each crop.

Crop	Phytoseiidae	
	No. of Genera	No. of Species
Strawberry	3	3
Avocado	3	4
Cherimoya	4	5
Caneberry	7	7
Grape	7	12

Table 25. Total number of phytoseiid species identified on each crop.

Crop	Phytoseiidae						
	Phytoseiulus persimilis	*Neoseiulus californicus*	*Galendromus occidentalis*	*Galendromus annectans*	*Amblydromalus limonicus*	*Euseius quetzali*	*Euseius stipulatus*
	Type I	Type II	Type II	Type II	Type III	Type IV	Type IV
Strawberry	242	215	0	0	0	0	0
Avocado	0	0	0	0	0	0	117
Cherimoya	0	0	0	0	0	0	92
Raspberry	50	26	0	0	84	0	65
Blackberry	0	49	14	24	7	0	0
Grape	6	0	0	0	0	43	41
Total	298	290	14	24	84	43	315

CHAPTER VI

CONCLUSION

This survey found common pest-predator patterns and some unexpected deviations from those patterns. Pest-predator relationships were mostly found in one of three situations. The first was a typical pest-predator correlation where type I or type II phytoseiids responded to the presence of tetranychids and caused that population to decline. The second observation found tetranychid populations that did not decline in the presence of phytoseiids that included type I, II, III, and IV species. The third situation found groups of type III or type IV phytoseiid populations develop in the absence of tetranychids. More evidence of regulation was apparent with type I and type II phytoseiids species. The tetranychids most affected by type I and type II phytoseiids were *T. urticae* on strawberry and *T. urticae* and *Eotetranychus* spp. on raspberry. These tetranychid populations clearly declined when these phytoseiids appeared. The evidence suggests that growers would have more success releasing type I and type II phytoseiid species in a cropping system suited to their behavior and feeding habits.

Phytoseiid species presumed to be dominant in certain crops were either absent or present in lower than expected densities. *Euseius hibisci* was expected to be the dominant predator on avocado, but instead was notably absent from avocado and *E. stipulatus* was the dominant species. *Phytoseiulus persimilis* was expected to be the prominent species on caneberry and strawberry due to augmentative releases. Instead, type III *A. limonicus* and type IV *E. stipulatus* were the dominant phytoseiids on caneberry in 2006. *Phytoseiulus persimilis* was the most abundant species collected from caneberry and strawberry in 2007, but was still found in lower than expected numbers. Furthermore, *P. persimilis* was absent from blackberry in 2007 in spite of the presence of *T. urticae* and in spite the presence of *P. persimilis* on neighboring raspberry plants. The absence of *P. persimilis* on blackberry suggests that the individuals did not move from raspberry to blackberry in search of additional prey or other resources. The notable presence of type III *A. limonicus* on caneberry was of commercial interest to Koppert Biological Systems. Specimens were collected in June 2008 from site C1 and shipped for evaluation. Subsequent reporting states that a method for mass production was developed (Knapp et al., 2013) and *A. limonicus* was made commercially available in January 2012 under the trade name LIMONICA for control of thrips and whitefly.

The strawberry cropping system had the least diverse collection of phytoseiid species, but had the highest number of type I and type II predators, and therefore, provided the most consistent regulation. The two subtropical crops, avocados and cherimoya, were largely dominated by type IV *Euseius* species which did not control *O. perseae*. Raspberry and blackberry showed an unexpected difference in their respective phytoseiid complexes. Raspberry had a significant amount of each phytoseiid type while blackberry had only type II and type III phytoseiids. Yet, control of tetranychids pests was evident in each system with help from augmentative releases of *P. persimilis*. Grape had the greatest diversity of species identified, but many of those species were collected less than 5 times during any one season, and therefore, are not represented on Table 25. These vineyards contained mostly type IV *Euseius* species. The most discernable evidence of control in the vineyards was most likely the result of pesticide applications.

Galendromus occidentalis has been widely accepted as the most common naturally occurring species in California cropping systems in recent years. However, this survey found far more diversity than was expected. Further research is needed to better understand the behavior of the many species that exist in different cropping systems to improve recommendations for biological control and pest management decisions. The work should be conducted in a controlled environment, in the absence of pesticides, to better understand their natural behavior and seasonal trends. More work is also needed to identify type I and type II species that would be suitable biological control agents in avocado, cherimoya, and grape. Establishing economic thresholds for *O. perseae* on avocado, *Eotetranychus* spp. on cherimoya, *T. urticae* and *Eotetranychus* spp. on caneberry, and *E. willamettei* on grape would also benefit the agriculture industry.

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Appendix A

Taxonomy of *Phytoseiidae*

Subfamily*: Amblyseiinae*

Genus: *Amblydromalus*

Dorsal setae are short except for s4. Setae j6 are less than twice the length of the distance between the two bases. Setae Z4 is minute and does not extend to the base of Z5. The ventrianal shield is vase shaped and has 1-3 pairs of preanal setae. The cervix of the spermatheca is the shape of a long tube. The peritreme is long and extends to the base of seta j1. The cheliceral digits have 6-10 evenly spaced teeth.

Amblydromalus limonicus

Amblydromalus limonicus is the only species in the key listed for this genus and there are no specific characters listed beyond those described for the genus.

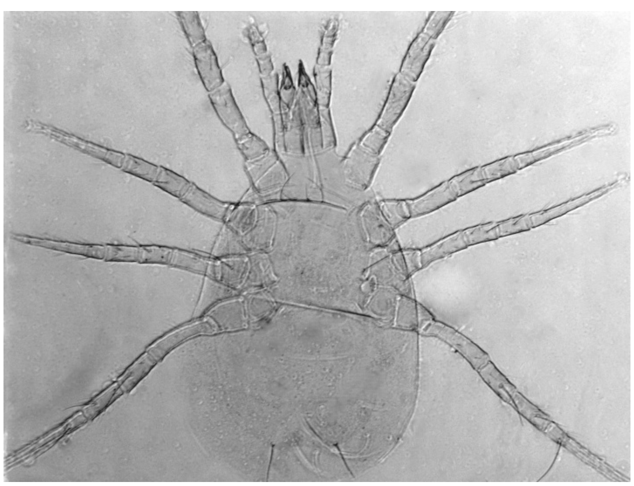

Figure A1. Slide mounted *Amblydromalus limonicus.*

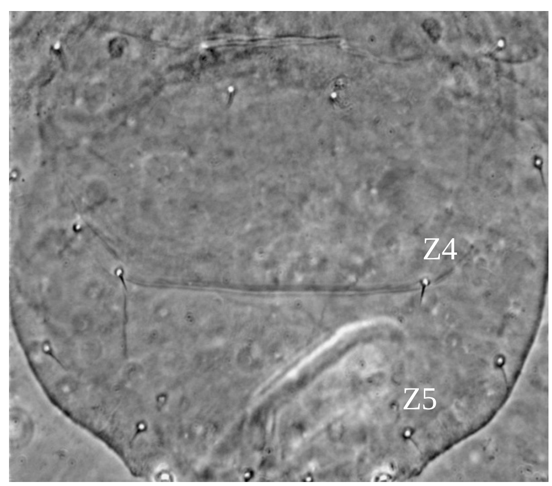

Figure A2. Minute Z4 does not reach to the base of Z5, *Amblydromalus limonicus.*

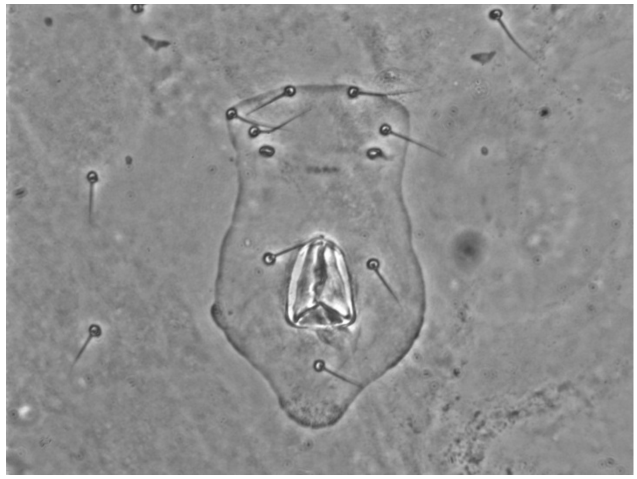

Figure A3. Ventrianal shield, *Amblydromalus limonicus.*

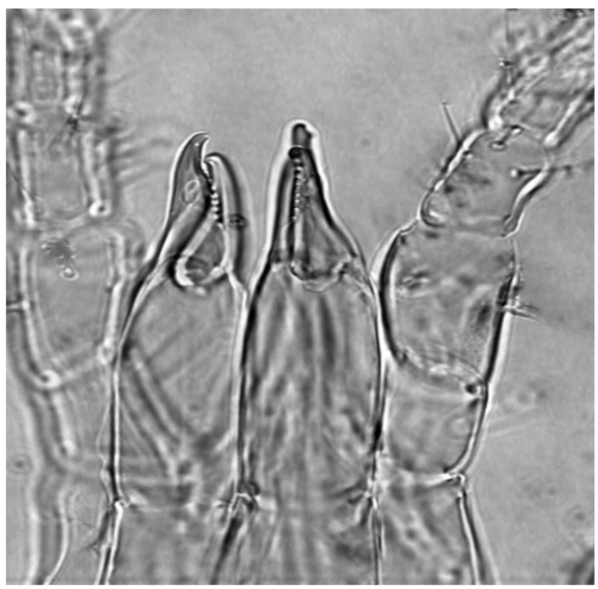

Figure A4. Cheliceral digits with 6-10 teeth, *Amblydromalus limonicus.*

Genus*: Amblyseius*

Setae j6 are less than twice the length of the distance between the two bases. Setae s4 are longer than Z1. Setae J2 are present. The ventrianal shield has 1-3 pairs of preanal setae. The posterior edge of the sternal shield is straight or concave. The sternal and/or the ventrianal shield are not wider than longer. The atrium of the spermatheca is not elongate. The macroseta is always on leg II or III.

Amblyseius similoides

Setae are short except for s4 and Z4. The ventrianal shield is pentagonal in shape. The cervix of the spermatheca flares distally and narrows toward the basal portion. The fixed digit has small teeth on both sides of the pilus dentilis.

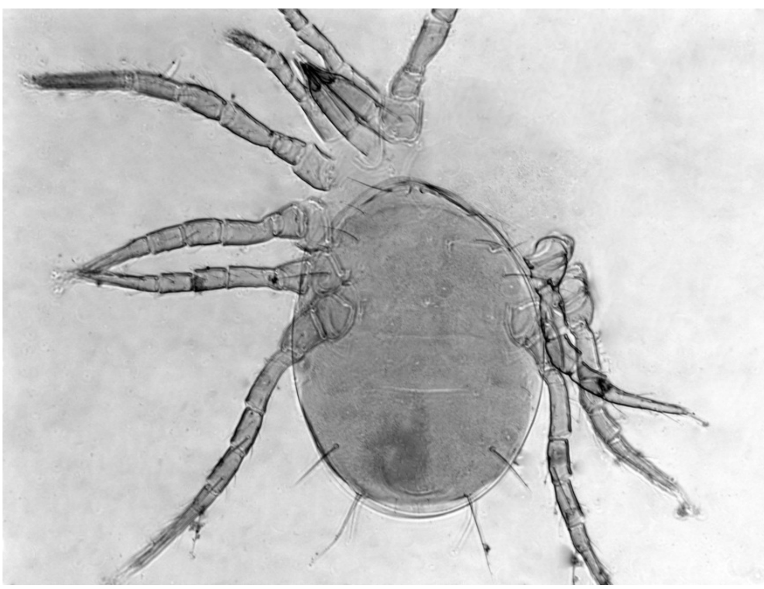

Figure A5. Slide mounted *Amblyseius similoides*.

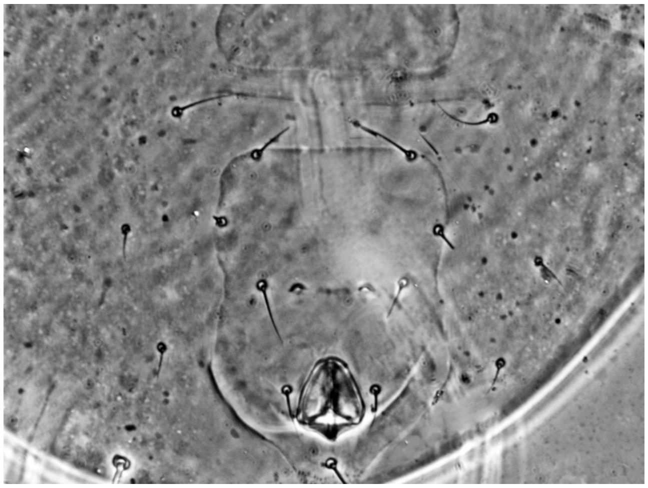

Figure A6. Pentagonal shaped ventrianal shield, *Amblyseius similoides*.

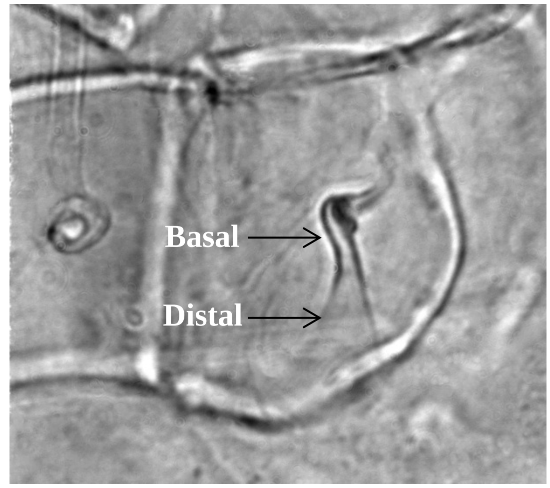

Figure A7. Spermatheca flares distally, *Amblyseius similoides.*

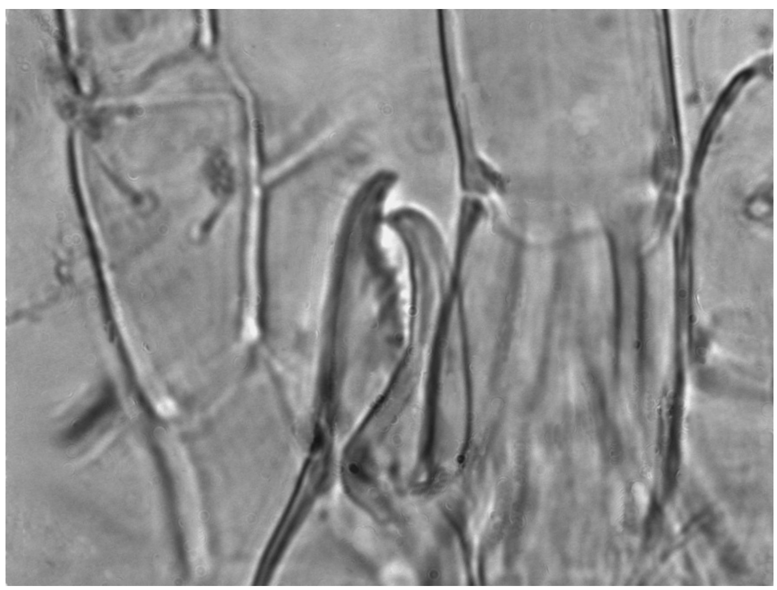

Figure A8. Cheliceral digit with multiple teeth, *Amblyseius similoides.*

Genus: *Euseius*

Euseius species have a short peritreme that does not reach setae ji. Setae j6 are short; the length is less than twice the distance between their bases. The genital shield is vase-shaped and the posterior edge of the genital shield is wider than the anterior edge of the ventrianal shield. The cheliceral digits are short with small teeth.

Euseius hibisci

Setae r3 is located on the integument of the dorsal shield. Setae z4 is nearly twice the length of Z4. The cervix of the spermatheca is long and tube-shaped. The macrosetae on the basitarsal IV has a sharp tip.

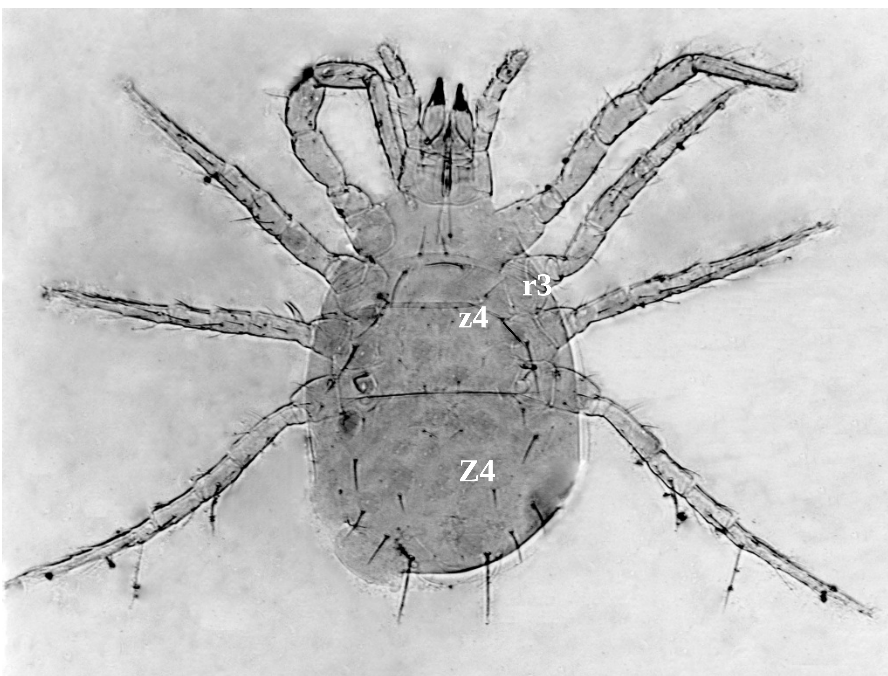

Figure A9. *Euseius hibisci* - setae z4 is slightly longer than Z4 and r3 is located on the integument of the dorsal shield.

Figure A10. Spermatheca with long tube-shaped cervix, *Euseius hibisci*.

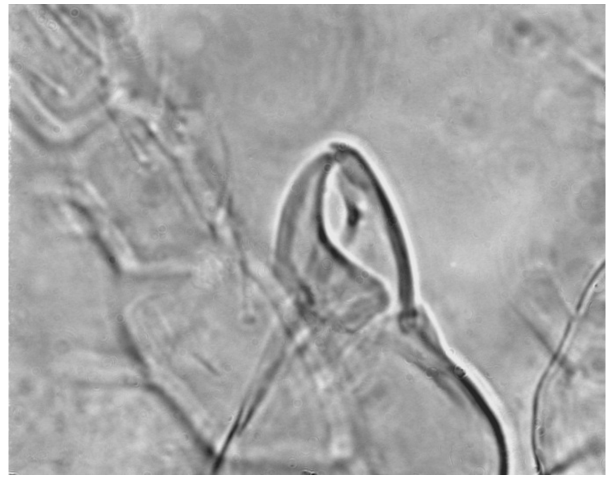

Figure A11. Short cheliceral digit, *Euseius hibisci*.

Figure A12. Macroseta with sharp tip, *Euseius hibisci.*

Euseius quetzali

Seta r3 are located on the integument of the dorsal shield, not directly on the dorsal shield. The cervix of the spermatheca resembles a long tube. Macrosetae on the basitarsal IV have sharp tips. Setae z4 are slightly longer than Z4.

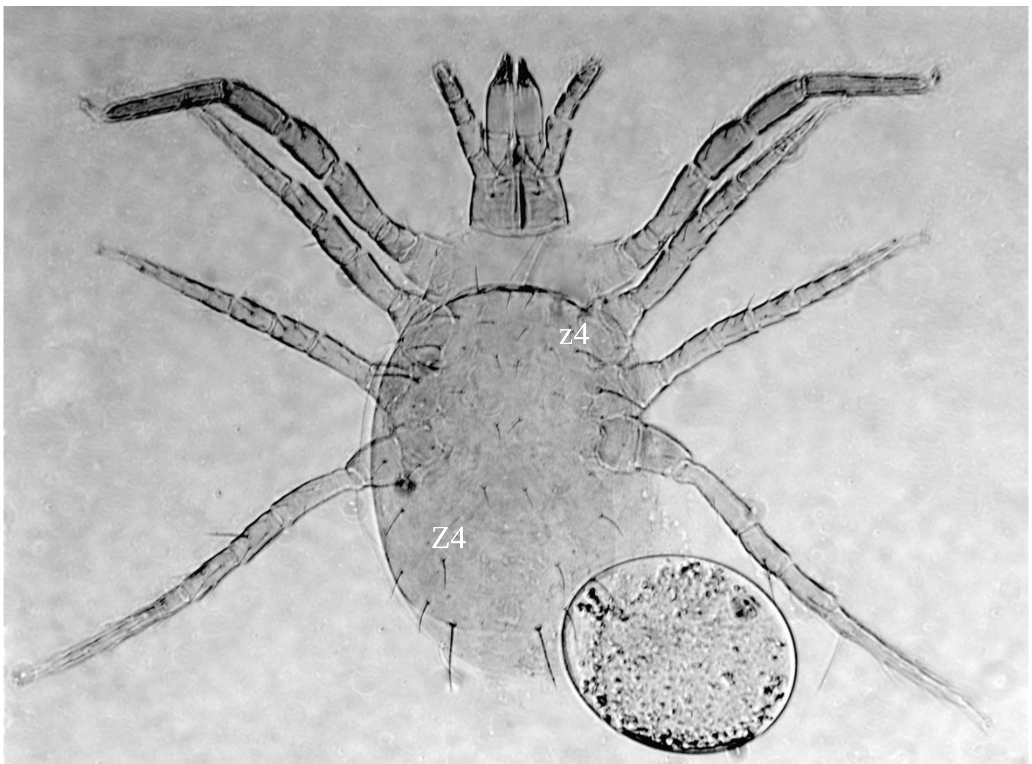

Figure A13. Setae z4 is slightly longer than Z4, *Euseius quetzali*.

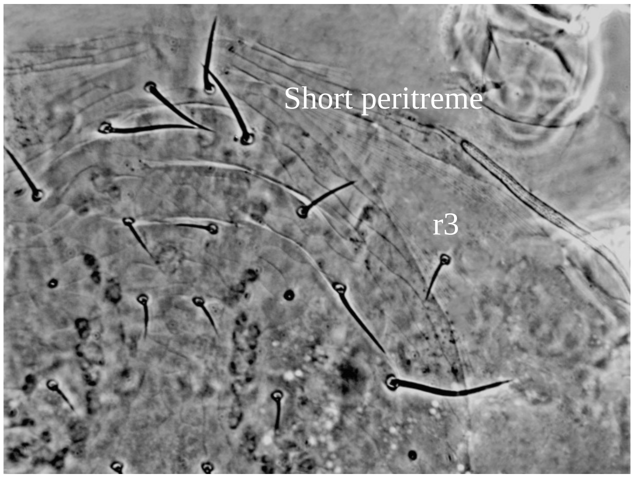

Figure A14. Short peritreme and seta r3 on the integument of the dorsal shield, *Euseius quetzali*.

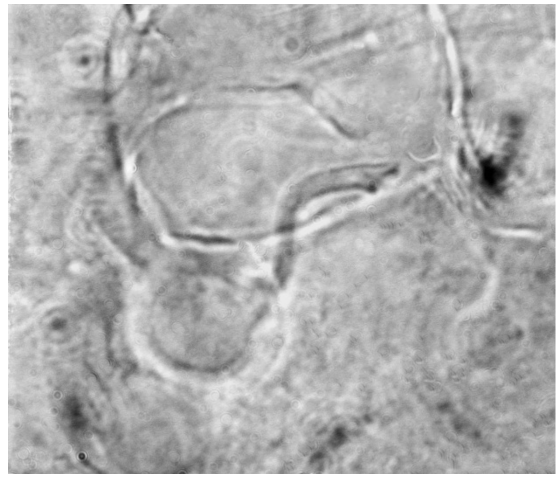

Figure A15. Spermatheca with long tube-shaped cervix with flared tip, *Euseius quetzali*.

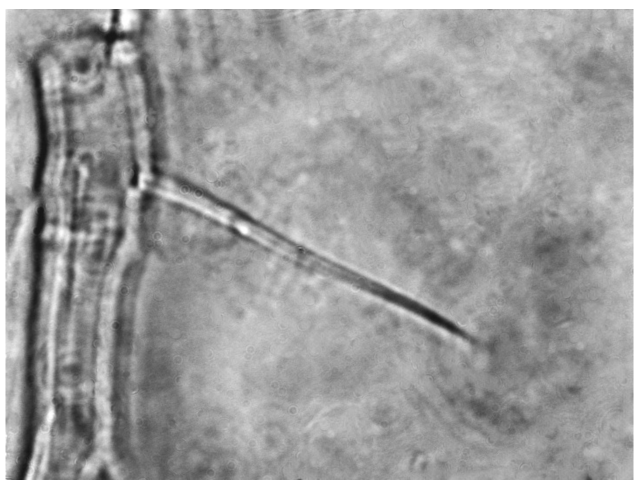

Figure. A16. Macroseta with sharp tip, *Euseius quetzali*.

Euseius stipulatus

Setae r3 are located on the integument of the dorsal shield, not directly on the dorsal shield. The cervix of the spermatheca is short and tube-shaped. The macrosetae on the basitarsal IV have blunt tips.

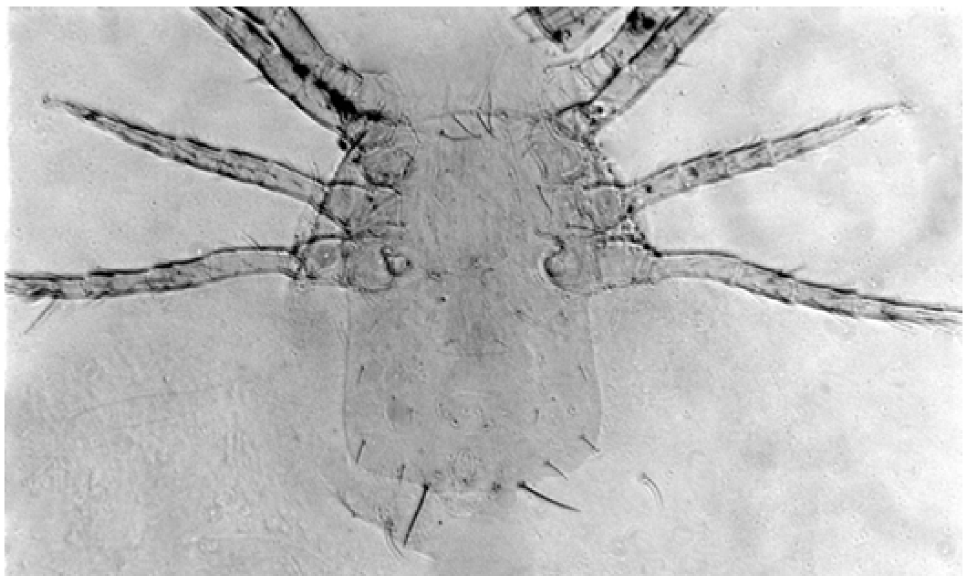

Figure A17. Slide mounted *Euseius stipulatus*.

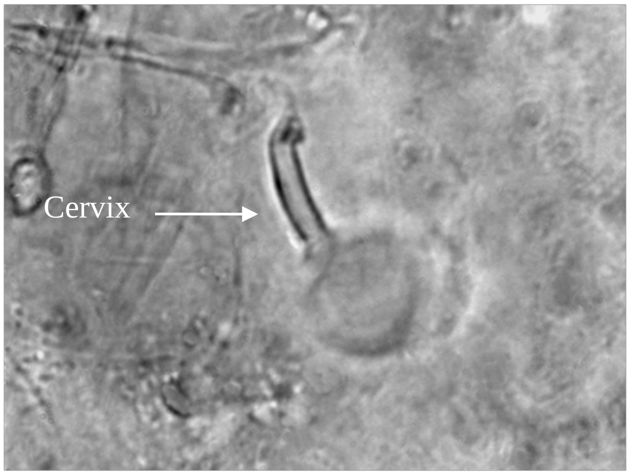

Figure A18. Spermatheca with short cervix, *Euseius stipulatus.*

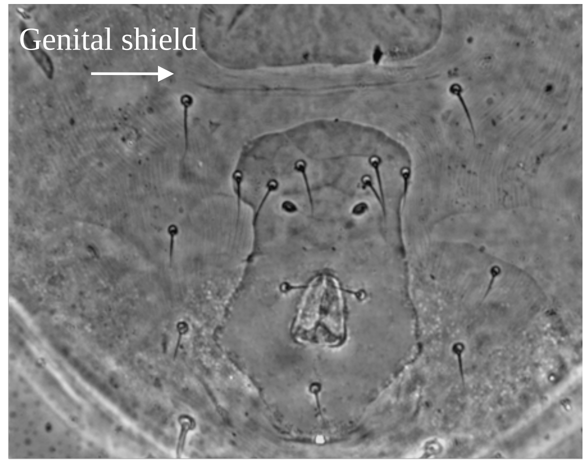

Figure A19. Posterior end of the genital shield is wider than the anterior head of the ventrianal shield, *Euseius stipulatus.*

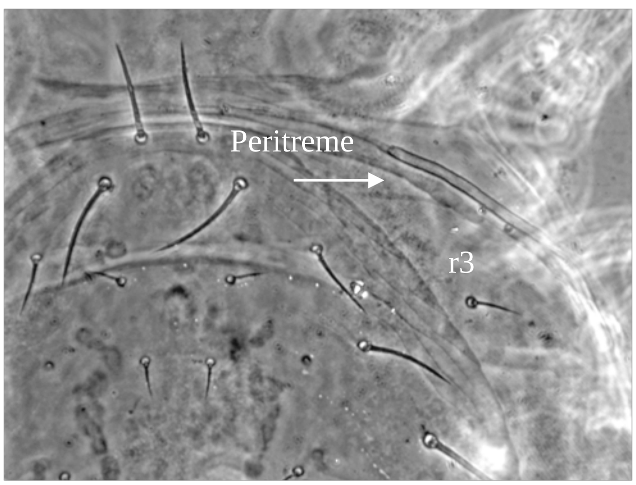

Figure A20. Short peritreme and seta r3 in the integument of the dorsal shield, *Euseius stipulatus.*

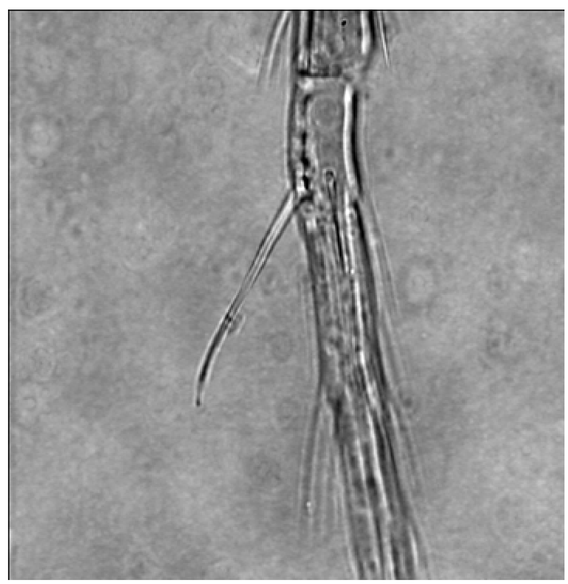

Figure A21. Blunt tip of the macroseta on basitarsal IV, *Euseius stipulatus.*

Euseius tularensis

There are few reticulations on the dorsal shield. Setae r3 is inserted on the lateral edge of the dorsal shield and the peritreme extends to z2 or to the middle of coxa II.

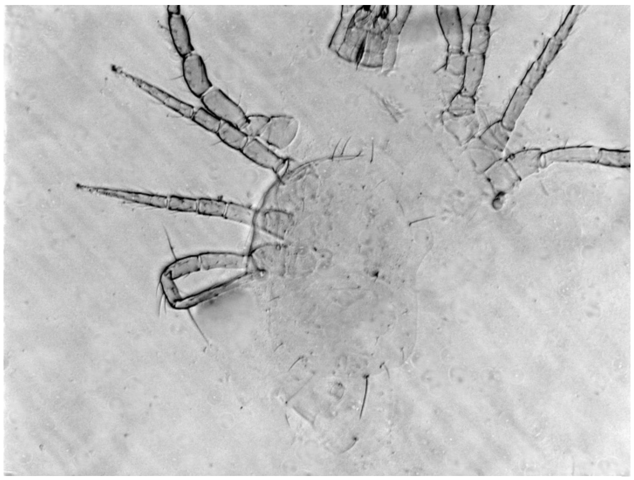

Figure A22. Slide mounted *Euseius tularensis.*

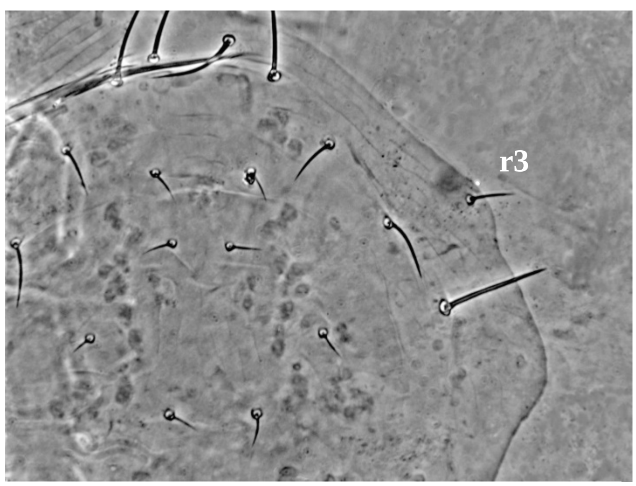

Figure A23. Seta r3 inserted on the dorsal shield of *Euseius tularensis.*

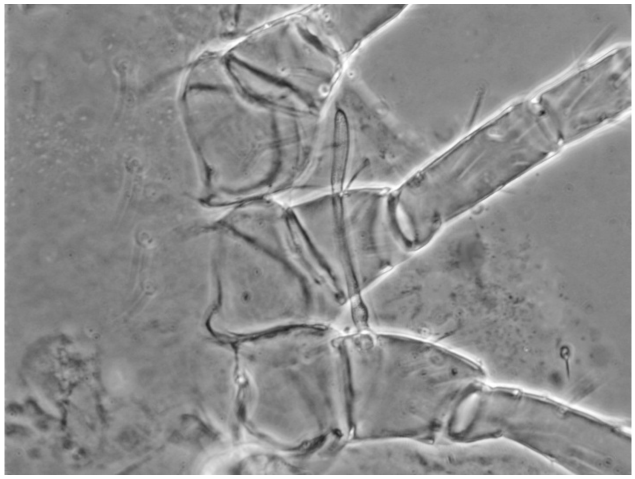

Figure A24. Short peritreme reaching to the middle of coxa II of *Euseius tularensis.*

Genus: *Neoseiulus*

Setae j6 setae are less than twice as long as the distance between their bases. Setae s4 is not significantly longer than Z1. The ventrianal shield has 1-3 preanal setae and is pentagonal. The anterior edge is wider than the posterior edge of the genital shield. The posterior edge of the sternal shield is straight or concave. Macrosetae occur only on leg IV.

Neoseiulus aurescens

The spermatheca is distinctly constricted at the base of the atrium. The atrium is at least as wide as the cervix. The cervix is horn-shaped and its length is equal to or more than its width. Three pairs of preanal setae are present. The long peritreme reaches nearly to the base of seta j1.

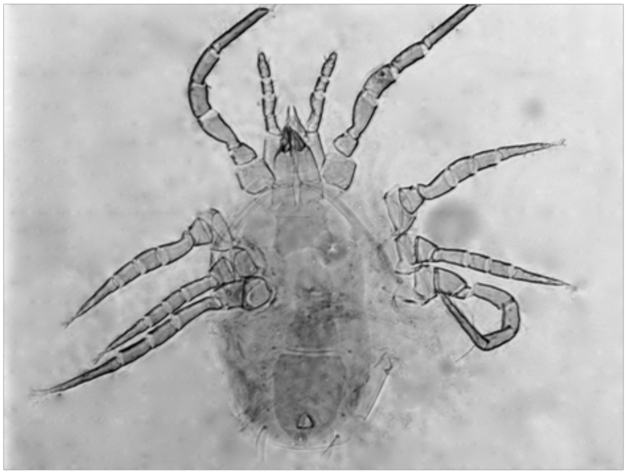
Figure A25. Slide mounted *Neoseiulus aurescens*.

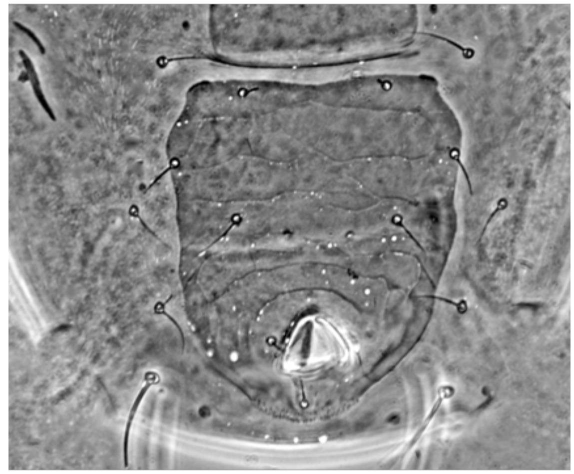
Figure A26.Ventrianal shield, *Neoseiulus aurescens.*


Figure A27. Spermatheca, *Neoseiulus aurescens.*

Neoseiulus californicus

Three pairs of preanal setae are present and two crescentic pores are near the center of the ventrianal shield. The cervix of the spermatheca is cup shaped and its length is less than twice its width. The peritreme is long and extends to the base of setae j1.

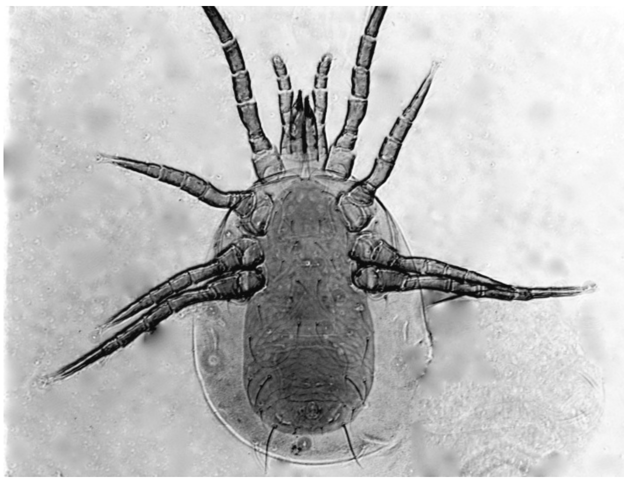

Figure A28. Slide mounted *Neoseiulus californicus.*

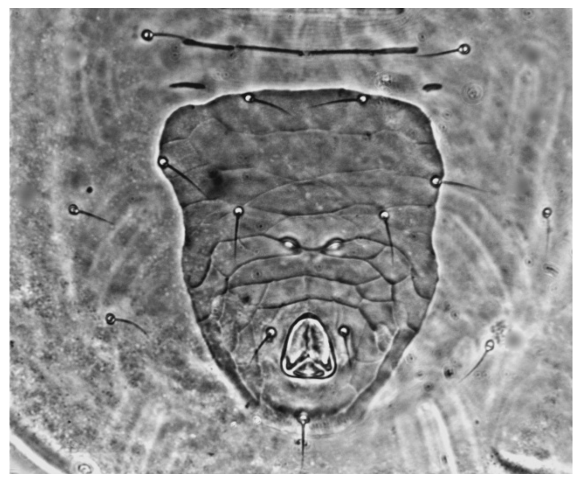

Figure A29. Ventrianal shield, *Neoseiulus californicus.*

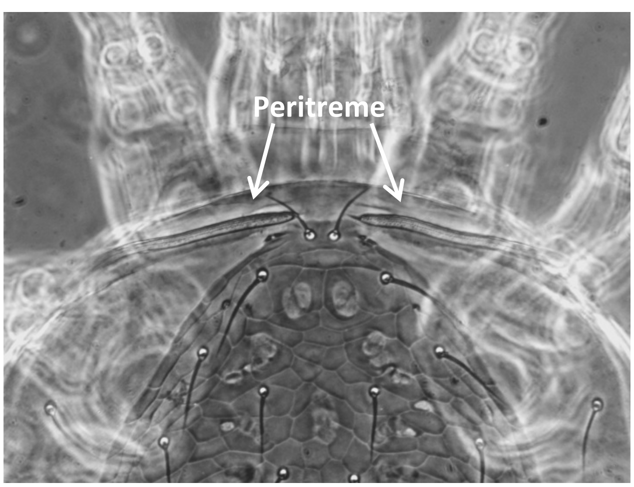

Figure A30. Long peritreme, *Neoseiulus californicus*.

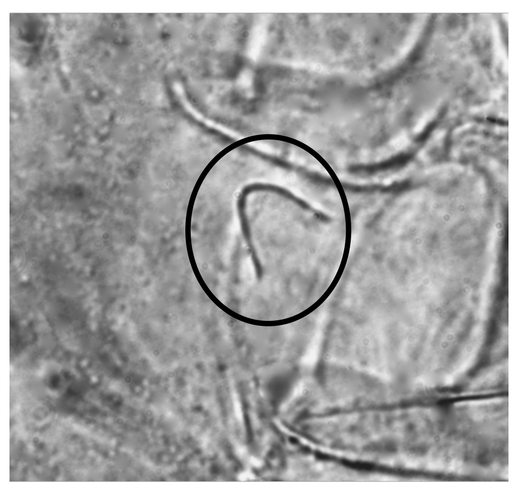

Figure A31. Spermatheca, *Neoseiulus californicus*.

Genus: *Phytoseiulus*

Long j6 setae are twice as long as the distance between their bases. The ventrianal shield has zero or one preanal setae. The spermatheca has a long narrow cervix that gradually flares then tapers at the basal end. The chelicerae have sharp teeth along the fixed and moveable digits.

Phytoseiulus persimilis

Preanal setae are absent and the ventrianal shield is round.

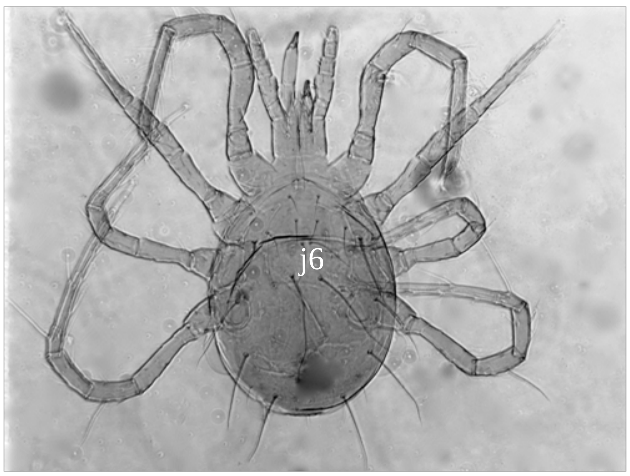

Figure A32. *Phytoseiulus persimilis* with long j6 setae.

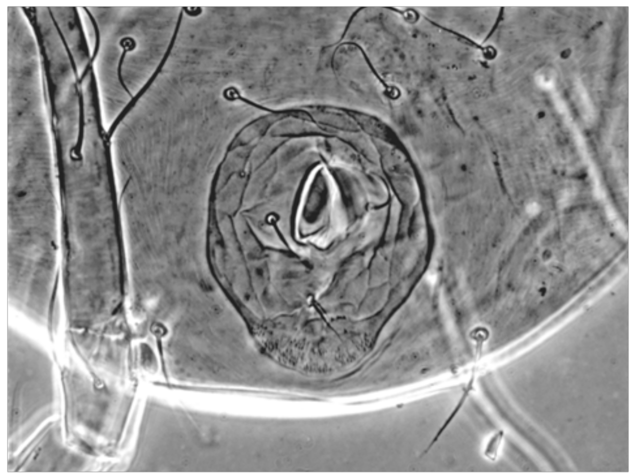

Figure A33. Ventrianal shield absent of preanal setae, *Phytoseiulus persimilis*.

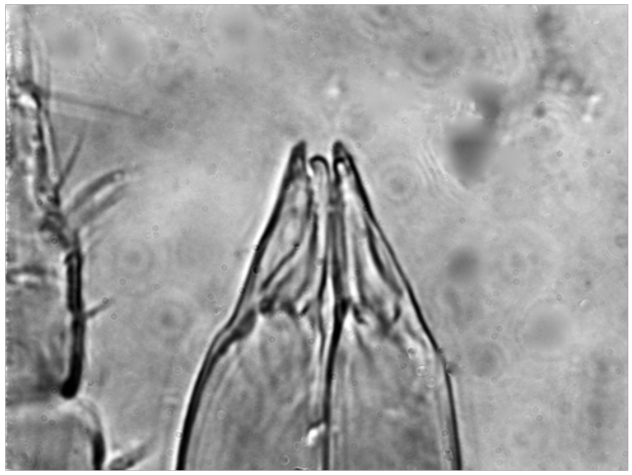

Figure A34. Chelicerae, *Phytoseiulus persimilis*.

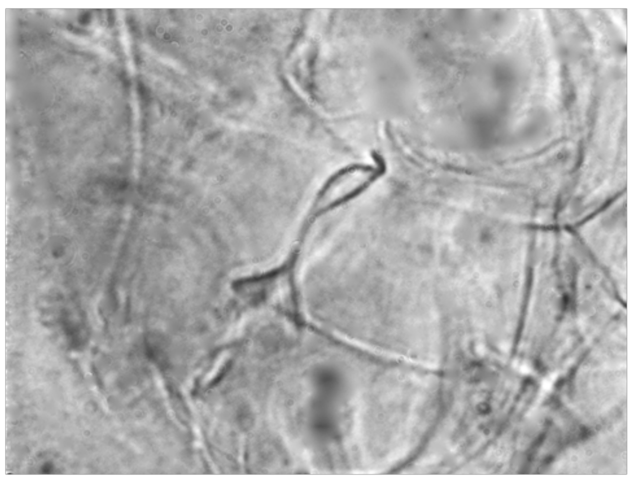

Figure A35. Spermatheca, *Phytoseiulus persimilis*.

Subfamily: *Typhlodrominae*

Genus: *Galendromus*

Galendromus species are characterized by the location, presence and absence of different seta. The base of j3 is closer to the base of j1 than to the base of z2. Seta S5 is present and located at an equal distance between Z4 and Z5. Seta S2 is present and R1 is absent.

Galendromus annectans

The length of seta j4 is greater than or equal to the distance between it and the base of j5. The peritreme is short and only reaches to the base of z3. The length of z5 is similar to that of j4, j5 and j6. The cervix is long and tube shaped. The moveable digit has one tooth and the fixed digit has a prominent pilus dentilis and three teeth near the terminal hook.

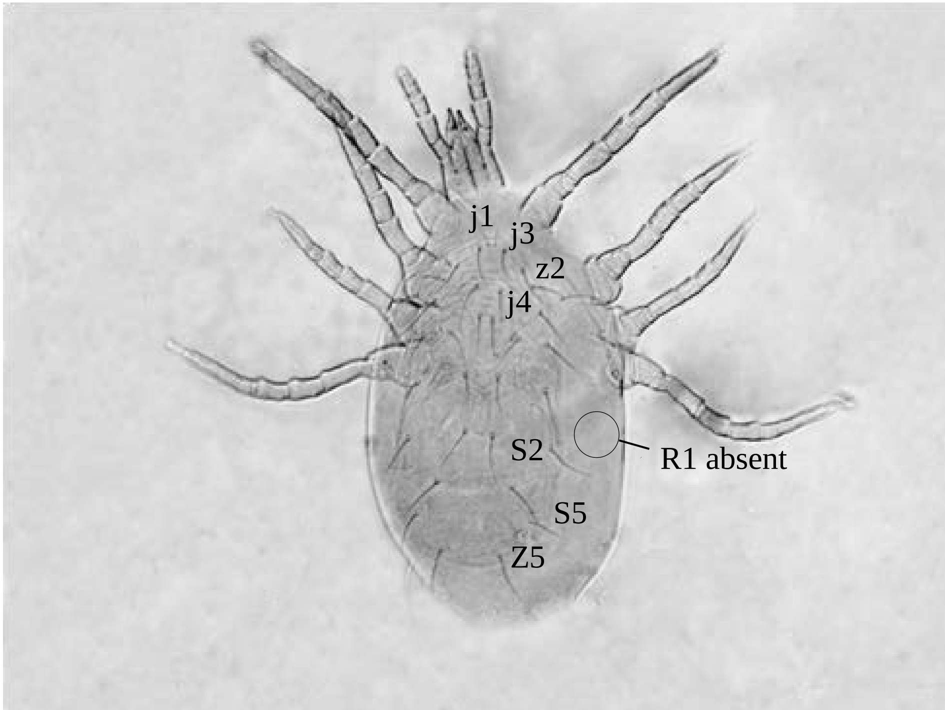

Figure A36. *Galendromus annectans* with seta R1 absent.

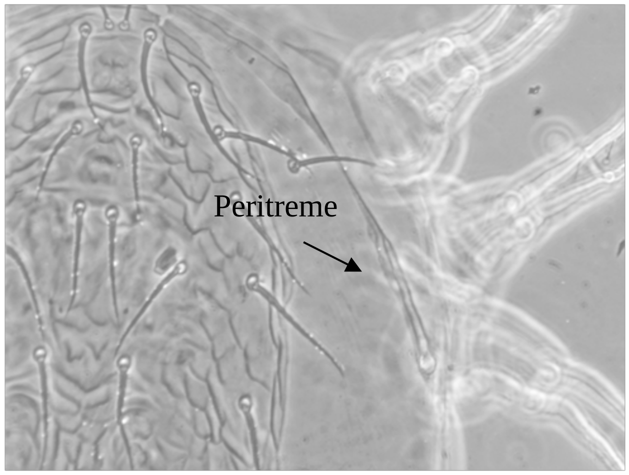

Figure A37. Short peritreme of *Galendromus annectans*, slightly longer than *G. occidentalis.*

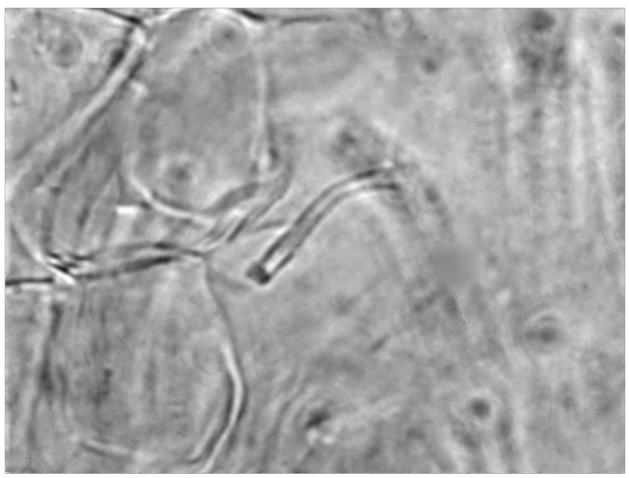

Figure A38. Spermatheca with long, tube-shaped cervix, *Galendromus annectans.*

Galendromus occidentalis

The peritreme is shorter in length than *G. annectans* and extends only to the level of seta s4. The cervix is long and tube shaped. The moveable digit has one tooth and the fixed digit has three teeth near the terminal hook.

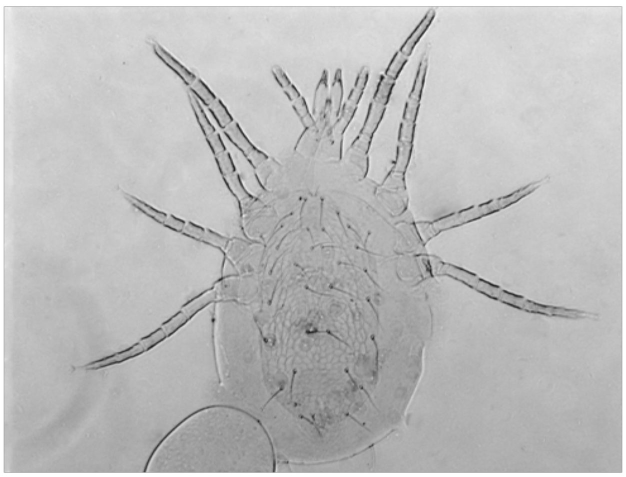

Figure A39. Slide mounted *Galendromus occidentalis.*

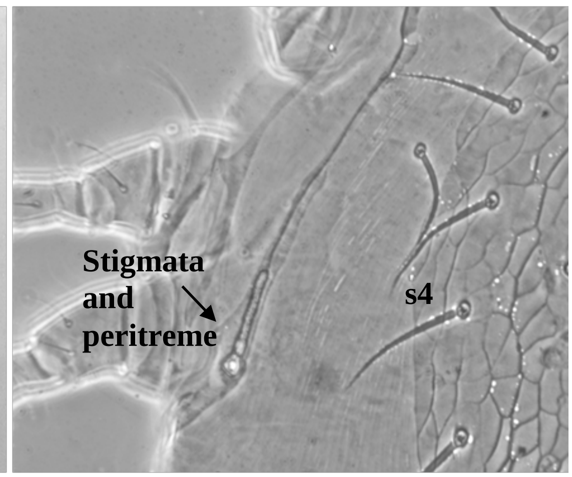

Figure A40. Short peritreme only extends to the level of s4, *Galendromus occidentalis.*

Figure A41. Ventrianal shield, *Galendromus occidentalis.*

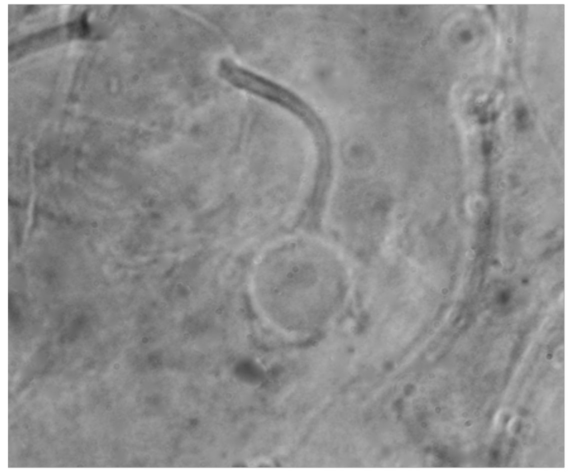

Figure A42. Spermatheca with long, tube-shaped cervix, *Galendromus occidentalis.*

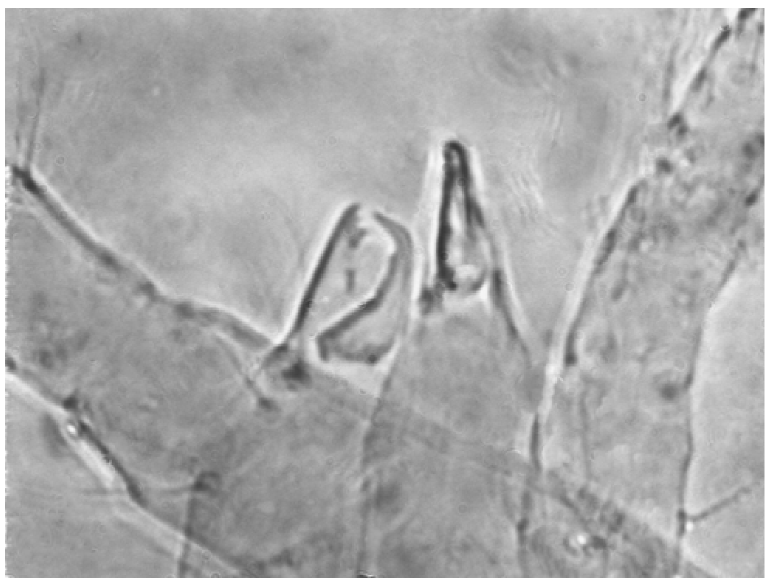

Figure A43. Fixed digit with three teeth near the terminal hook, *Galendromus occidentalis*.

Genus: *Metaseiulus*

This genus is separated into two groups, the pomi group and the pini group. Seta R1 is located on the dorsal shield in the pomi group and the pini group has seta R1 located on the integument of the dorsal shield. *Metaseiulus* species are characterized by the absence of setae z6, S2, S4, and JV4. Seta R1 is equal in length to s6. Seta S5 is less than half the length of Z5. The cervix of the spermatheca is funnel-like and gradually widens distally. These species also have indentions on the dorsal shield near setae S5.

Metaseiulus arboreus (pini group)

Setae Z4 nearly extends to the base of S5. Setae R1 is located on the integument of the dorsal shield. The ventrianal shield has four pairs of preanal setae and three pairs of ventrolateral setae. The cervix has a wider flare at distal end than other *Metaseiulus* species. The peritreme is long and extends nearly to the base of j1.

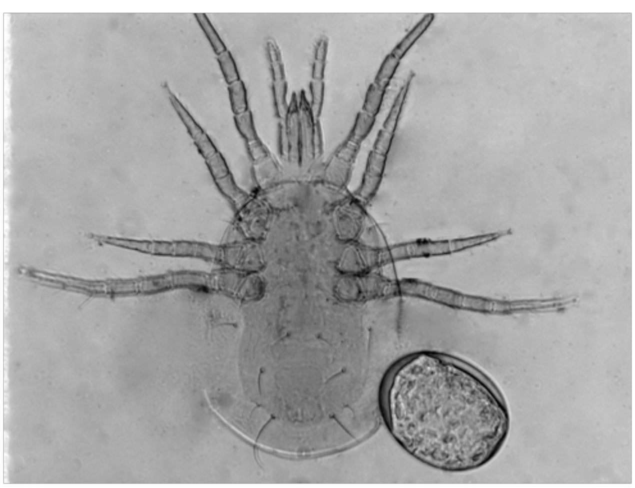

Figure A44. Slide mounted *Metaseiulus arboreus.*

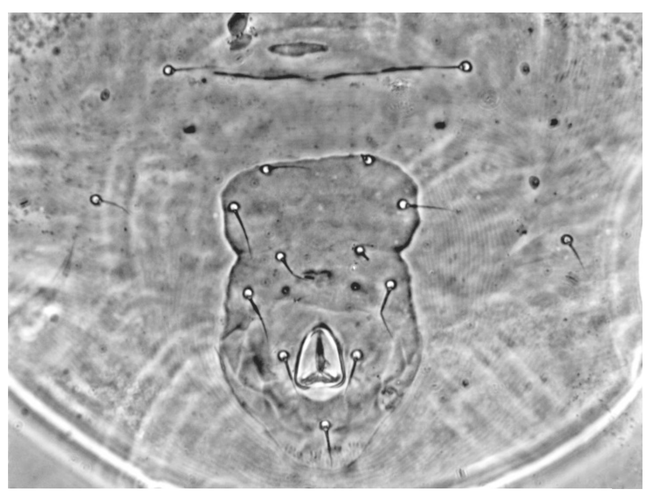

Figure A45. Ventrianal shield, *Metaseiulus arboreus.*

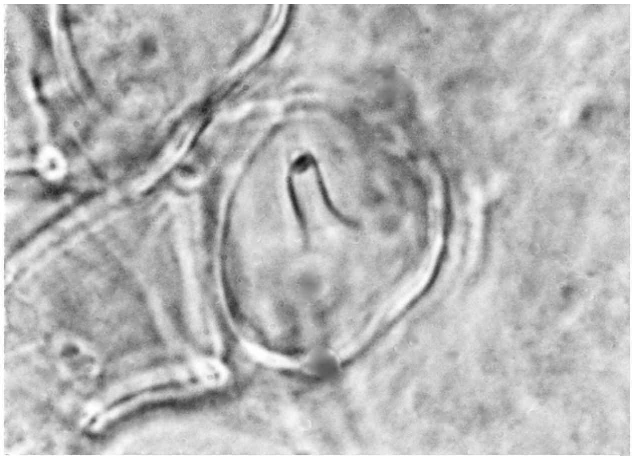

Figure A46. Spermatheca with short cervix, *Metaseiulus arboreus*.

Metaseiulus citri (pini group)

Seta R 1 is on the integument next to the dorsal shield. There are four pairs of preanal setae and two pairs of ventrolateral setae. The peritreme is long and extends nearly to the base of j1.

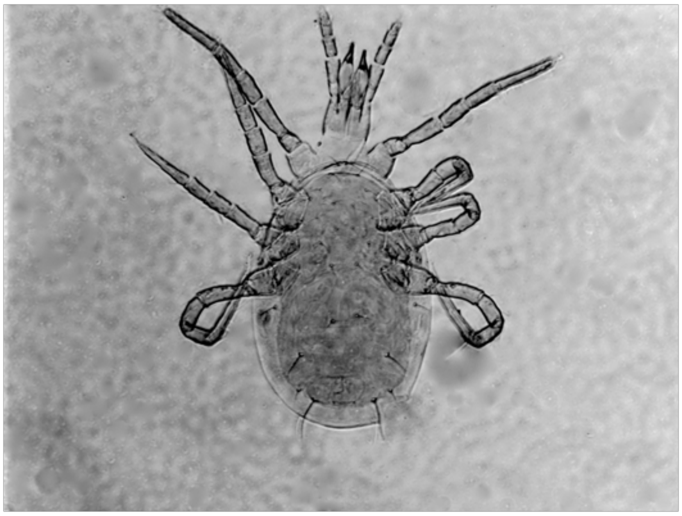

Figure A47. Slide mounted *Metaseiulus citri*.

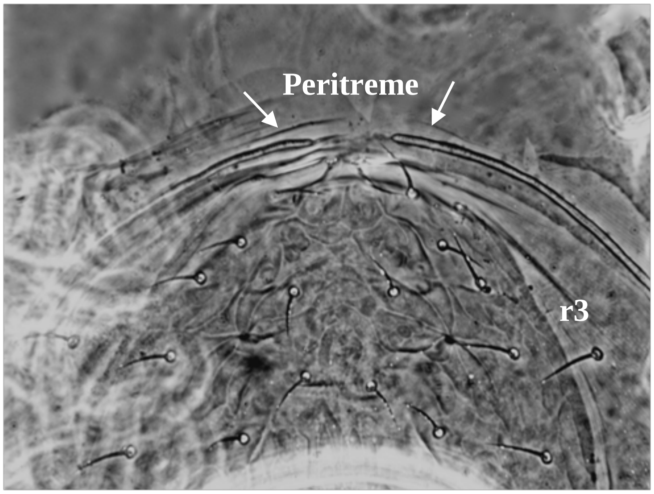

Figure A48. Long peritreme and seta r3 on integument of dorsal shield of *Metaseiulus citri*.

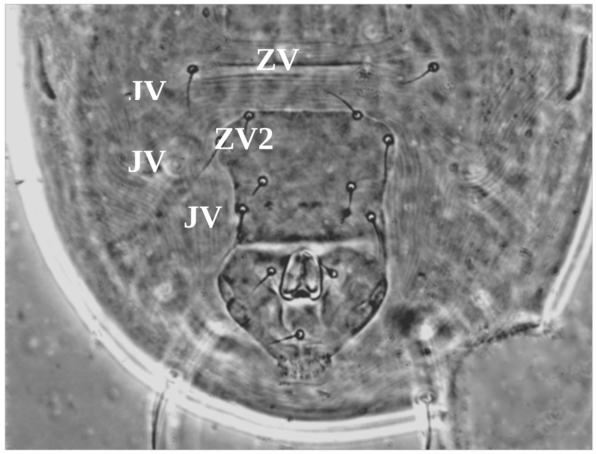

Figure A49. Ventrianal shield, *Metaseiulus citri*.

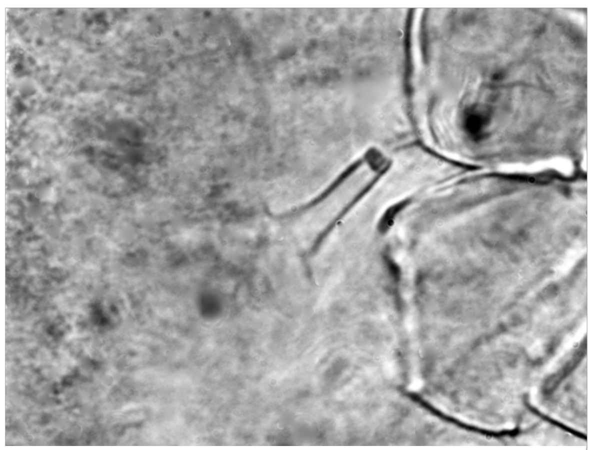
Figure A50. Spermatheca, *Metaseiulus citri*.

Metaseiulus flumenis (pomi group)

Seta R1 is located on the dorsal shield. The ventrianal shield is vase-shaped and has only two pairs of ventrolateral setae, ZV1 and JV5; seta ZV3 is absent. The peritreme is long and extends nearly to the base of j1. The fixed digit has two teeth near the terminal hook and the moveable digit has one tooth opposite the pilus dentilis.

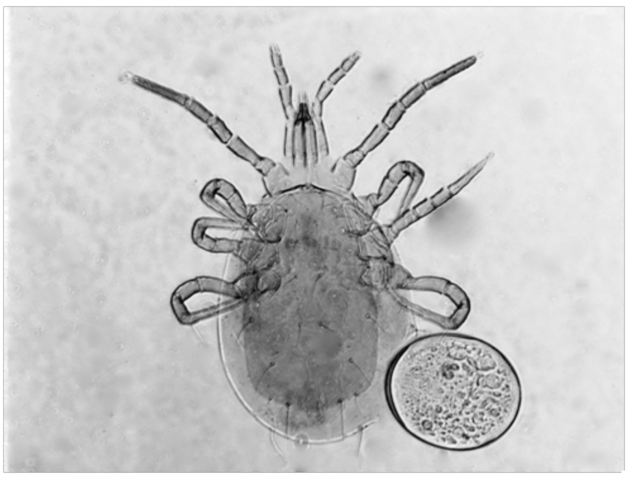

Figure A51. Slide mounted *Metaseiulus flumenis*.

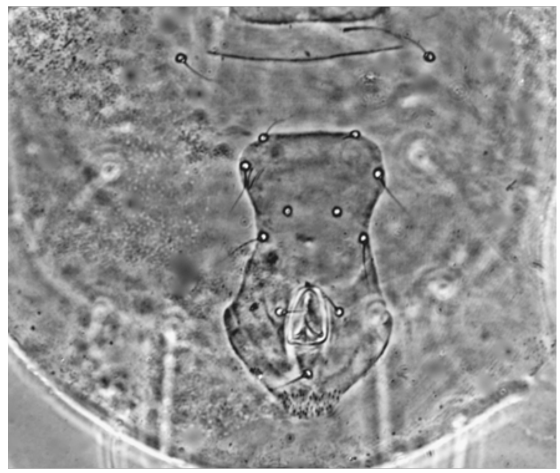

Figure A52. Ventrianal shield *Metaseiulus flumenis*.

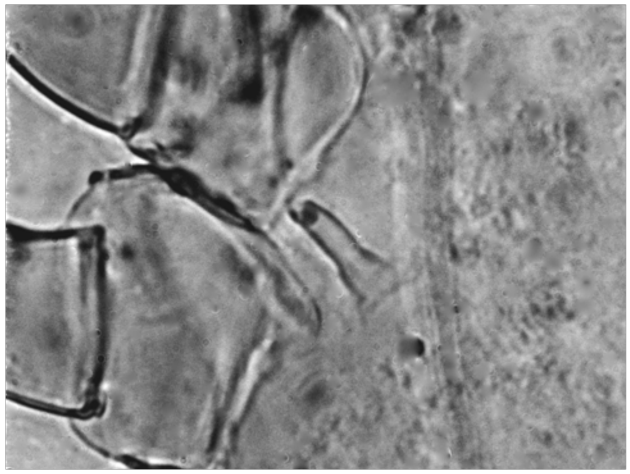

Figure A53. Spermatheca, *Metaseiulus flumenis*.

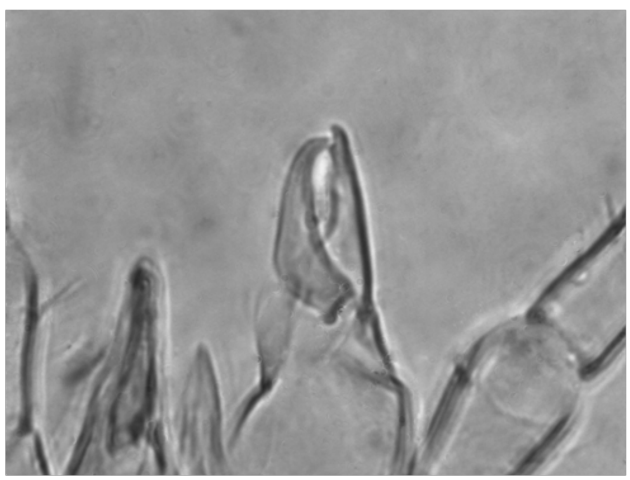

Figure A54. Cheliceral digit with one tooth near the terminal hook, *Metaseiulus flumenis.*

Metaseiulus johnsoni (pomi group)

Seta R1 is located directly on the dorsal shield. The length of Z5 is twice that of s6. The ventrianal shield has four pairs of preanal setae and three pairs of ventrolateral setae.

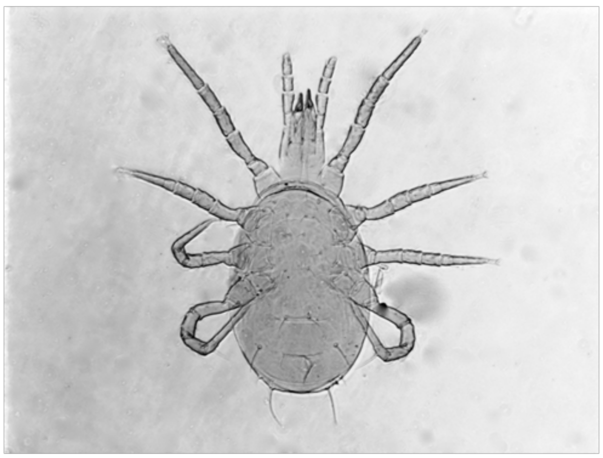

Figure A55. Slide mounted *Metaseiulus johnsoni*.

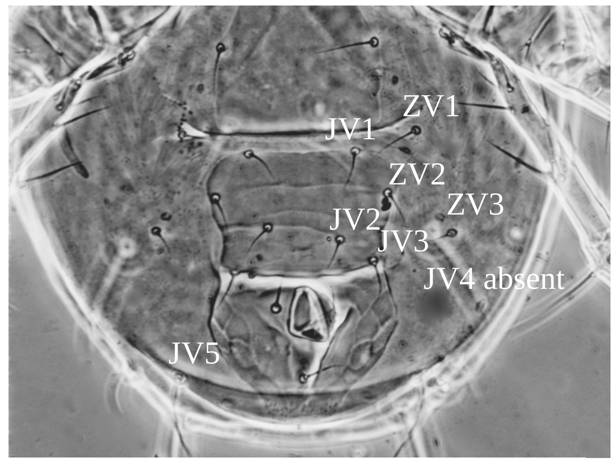

Figure A56. Ventrianal shield with seta JV4 absent, *Metaseiulus johnsoni*.

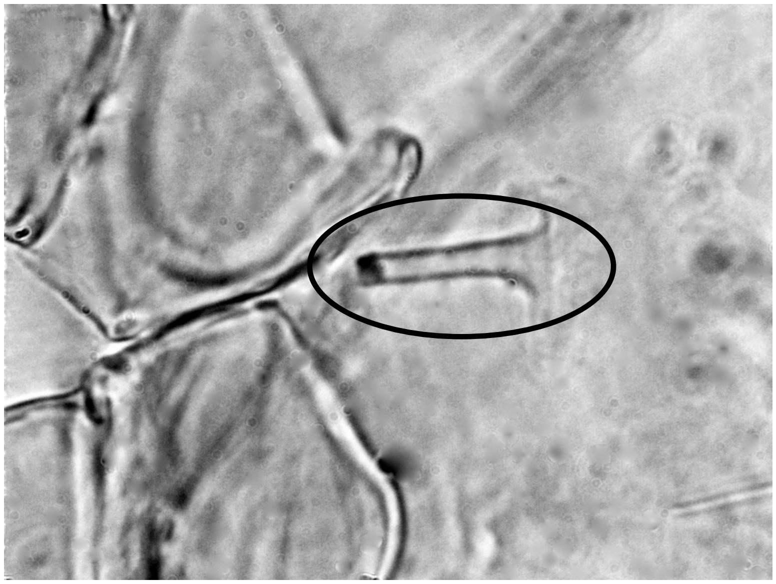

Figure A57. Spermatheca, *Metaseiulus johnsoni*.

Genus: *Typhlodromina*

Typhlodromina species lack setae z6, S2, S4, JV4. Setae j3 are located equidistant between the bases of j1 and z2 or may be closer to z2. Setae R1 are shorter than s6 and setae S5 and Z5 are equal in length. The cervix of the spermatheca is tube shaped with parallel sides. The peritreme is long and reaches to the base of j3. The moveable digit has one tooth and the fixed digit has one tooth near the terminal hook.

Typhlodromina eharai

Typhlodromina eharai is the only species listed in the key and no additional characters are identified beyond those described for the genus.

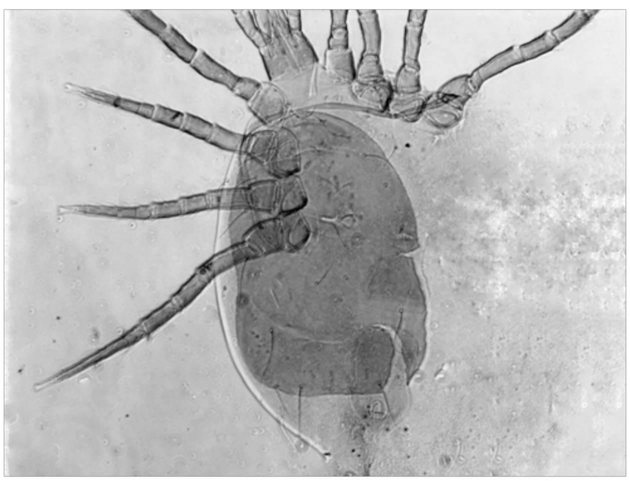

Figure A58. Slide mounted *Typhlodromina eharai.*

Figure A59. Tube shaped spermatheca with parallel sides, *Typhlodromina eharai.*

Figure A60. Ventrianal shield, *Typhlodromina eharai.*

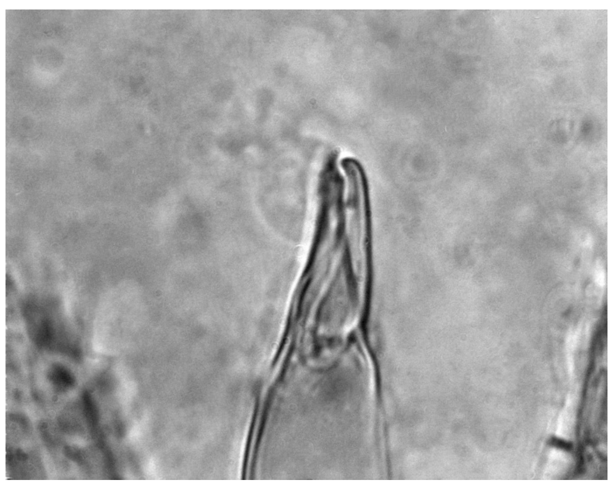

Figure A61. Cheliceral digit with one tooth near the terminal hook, *Typhlodromina eharai*.

Genus: *Typhlodromus*

*S*etae z6 is absent. Setae j3 are located midway between j1 and z2. Setae R1, S2, S4 and JV4 are present.

Typhlodromus rhenanoides

Setae S5 is present. Basitarsus IV has a long macroseta with a knobbed tip. The cervix is tube shaped with parallel sides. The fixed digit has three subterminal teeth.

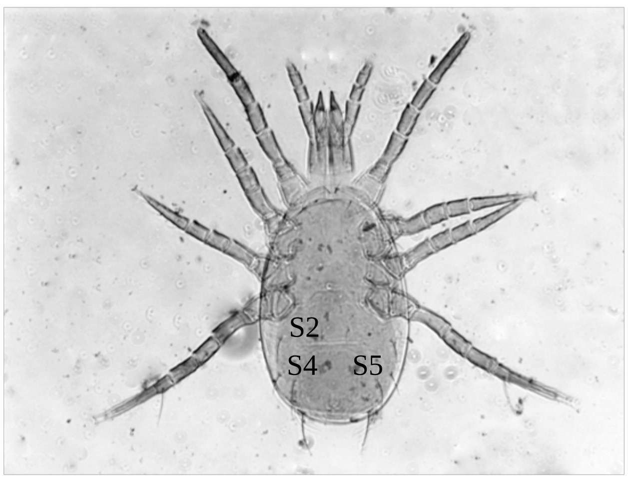

Figure A62. Slide mounted *Typhlodromus rhenanoides*.

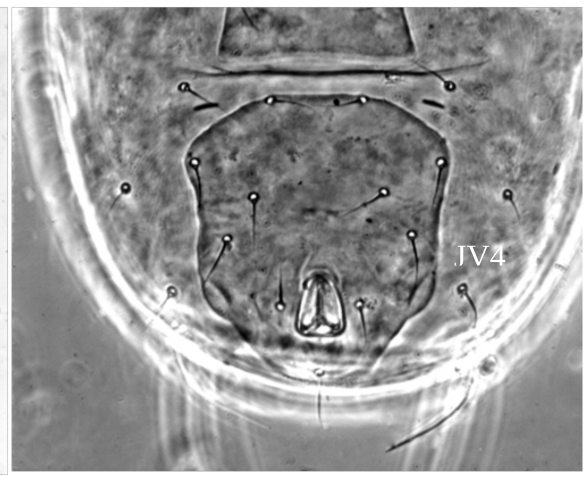

Figure A63. Ventral shield with seta JV4, *Typhlodromus rhenanoides*.

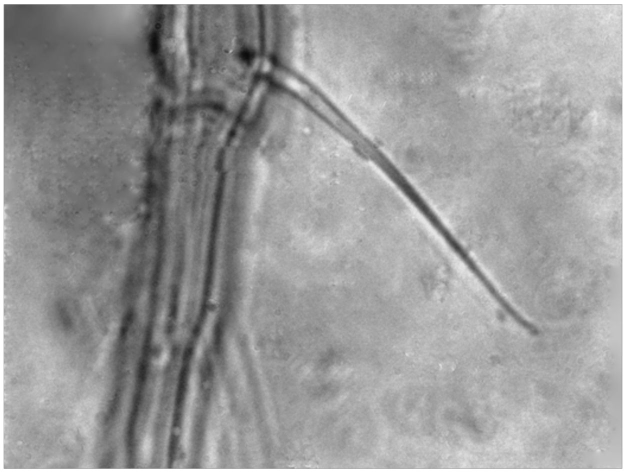

Figure A64. Long macroseta with knobbed tip, *Typhlodromus rhenanoides.*

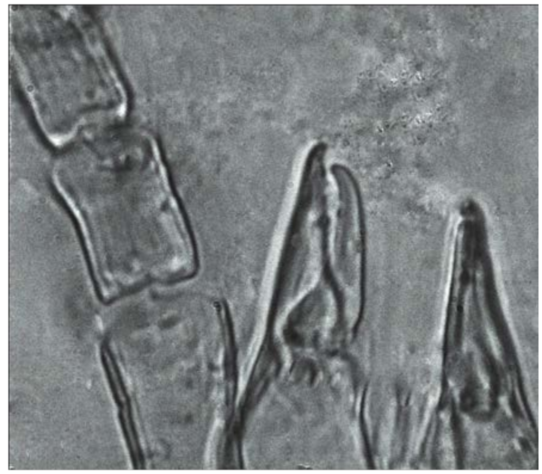

Figure A65. Cheliceral digits, *Typhlodromus rhenanoides.*

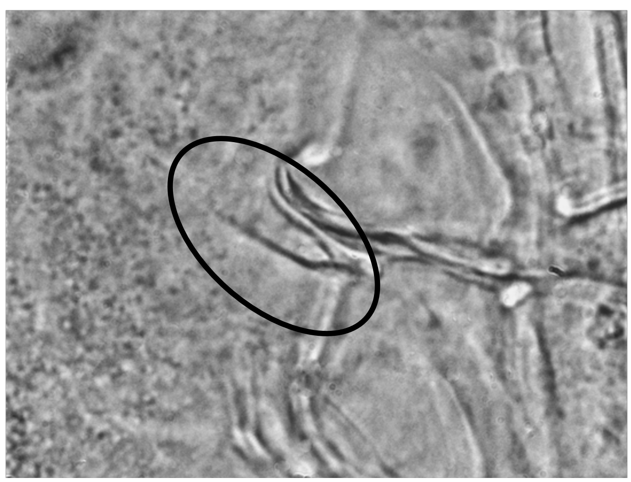

Figure A66. Spermatheca, *Typhlodromus rhenanoides.*